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TECHNICAL REPORT M-70-11

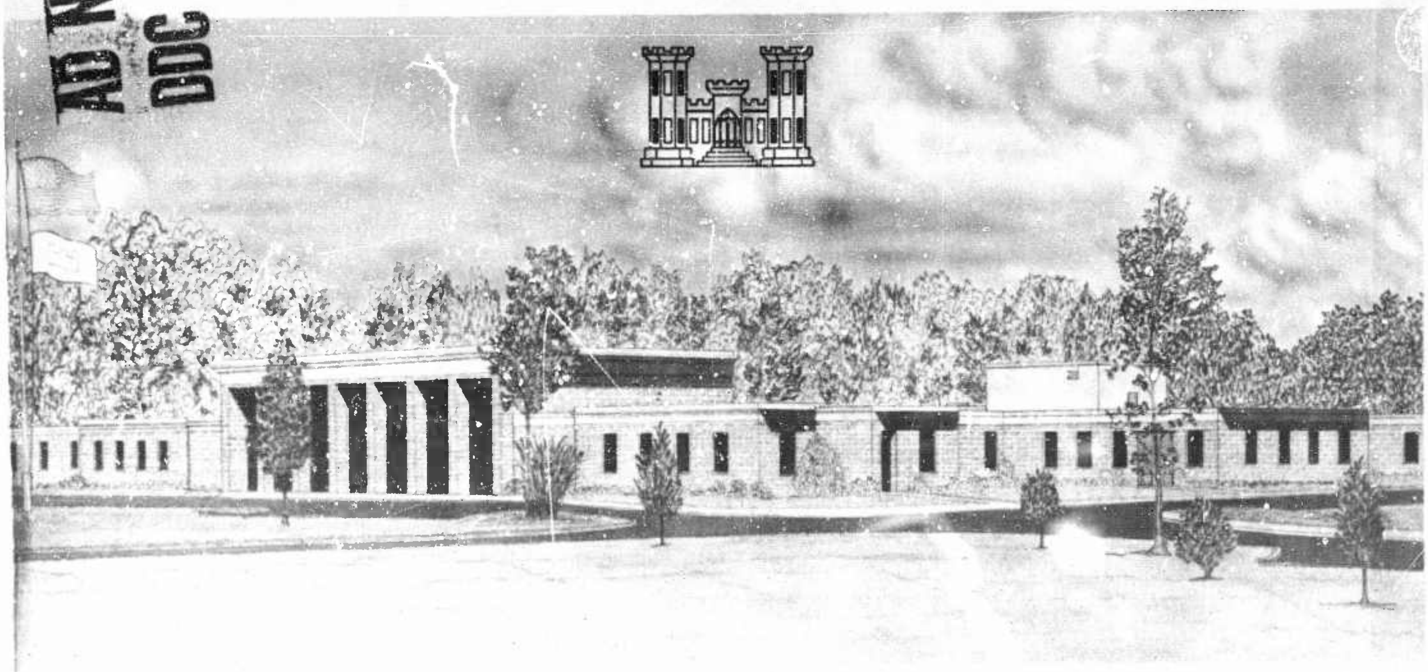
MOBILITY EXERCISE A (MEXA) FIELD TEST PROGRAM

Report 3

PERFORMANCE OF MEXA AND THREE MILITARY VEHICLES IN LATERAL OBSTACLES

by

J. L. Decell



July 1970

Sponsored by U. S. Army Materiel Command

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Materiel Command (AMC) and is part of the Mobility Exercise A (MEXA) program to evaluate the performance of three new vehicle concepts relative to the performance of three existing military vehicles. Funds for the MEXA program were provided under Project No. 1T062109A131, "Military Evaluation of Geographic Areas."

This study was conducted by personnel of the Vehicle Studies Branch under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief, Mobility and Environmental (M&E) Division; Mr. S. J. Knight, Assistant Chief, M&E Division; Mr. A. A. Rula, Chief, Vehicle Studies Branch; and Mr. J. K. Stoll, Chief, Obstacle-Vehicle Studies Section. Design and execution of the testing (conducted in June 1968) were under the direct supervision of Mr. J. L. Decell, Obstacle-Vehicle Studies Section. Data reduction and preparation of plates and tables were accomplished by Mr. T. D. Hutto under the direction of Mr. Decell, who performed the data analysis and prepared this report.

This is Report 3 of a series entitled "Mobility Exercise A (MEXA) Field Test Program."* The others are as follows: Report 1, "Summary"; Report 2, "Soft-Soil Performance of the MEXA Test Beds"; Report 4, "Performance of the MEXA and Three Military Vehicles in Selected Natural Terrains."

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* Two reports on this program have been published and they have been identified as Vicksburg Exercise A rather than Mobility Exercise A as indicated in this report.

CONTENTS

Directors of the WES during the conduct of this study and preparation of this report were COL John R. Oswalt, Jr., CE, COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Directors were Mr. J. B. Tiffany and Mr. F. R. Brown.

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square feet	0.092903	square meters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
feet per second	30.48	centimeters per second
miles per hour	1.609344	kilometers per hour

Note: Conversion from British to metric units of measure should be made with caution in this report in connection with rating cone index values.

SUMMARY

The purpose of this study was to develop pertinent vehicle-lateral obstacle relations for three vehicle test beds (MEXA vehicles) and three conventional military vehicles all having approximately the same payload and to compare the performances of the MEXA vehicles with those of the conventional vehicles. An additional purpose was to develop a method of predicting the speed of a vehicle maneuvering in lateral obstacles.

The vehicles were tested on a firm, level surface upon which was imposed a statistically designed array of obstacles at mean spacings of 14, 16, 18, and 20 ft. In 78 of the 118 tests conducted, continuous measurements were made of vehicle speed, drive-line torque, and steering angle. In all tests, measurements were made of time elapsed and distance traveled.

The data collected permitted the development of useful relations between vehicle width and minimum obstacle spacing negotiable, vehicle speed and obstacle spacing, vehicle steering angle and obstacle spacing, and vehicle speed and obstacle clearance. These relations were used to develop a simple method for relating the maximum speed a vehicle can develop to obstacle spacing that requires only a knowledge of the vehicle width and its speed-traction characteristics on a firm surface.

The conventional vehicles traveled faster and required less arduous steering than the MEXA vehicles. The maximum spacing required by each vehicle appeared to be a direct function of its width; all vehicles required the same minimum clearance on the driver's side.

Appendix A describes the use of speed-obstacle spacing relations as input data for an analytical model.

MOBILITY EXERCISE A (MEXA) FIELD TEST PROGRAM

PERFORMANCE OF MEXA AND THREE MILITARY VEHICLES IN LATERAL OBSTACLES

PART I: INTRODUCTION

Background

1. Forests have long been recognized as a major deterrent to cross-country travel. One of the specific factors affecting the free movement of a vehicle within a forest is the spacing of (i.e. the distance between) trees or other stems that are too sturdy for the vehicle to override and which therefore must be avoided by maneuvering laterally. Previous testing with vehicles in natural tree stands[1] has shown that the vehicle characteristics affecting speed performance in lateral obstacles are width, sweep (the width occupied by the vehicle hull during the negotiation of a turn), and the steering response rate of the driver-vehicle system.

2. A research program, Mobility Exercise A (MEXA), in progress at the U. S. Army Engineer Waterways Experiment Station (WES) attempts to examine a broad spectrum of the problems involved in the development of vehicle concepts for operation on low-strength soils in remote areas. As part of this program, three vehicle test beds have been designed and fabricated, and a plan of field tests has been developed. The requirements for the MEXA field test program are presented in a four-phase plan in Miscellaneous Paper No. 4-979.[2] Phase I consists of speed performance tests on a range of soil strengths beginning with the immobilization point of the three MEXA vehicles and three military vehicles up to and including performance on a hard surfaced road; Phase II calls for the establishment of engineering performance characteristics and essential terrain-vehicle relations; Phase III is a refinement or improvement of the terrain-vehicle relations required for the cross-country speed prediction model; and Phase IV comprises testing the capability of the updated cross-country speed prediction model through the use of data obtained during actual field testing

of the three MEXA and three military vehicles. The tests reported herein were conducted in partial fulfillment of the requirements of Phases II and III.

Purpose

3. The primary purpose of this study was to develop pertinent vehicle-lateral obstacle relations for the three vehicle test beds (hereinafter identified as MEXA vehicles) and three conventional military vehicles with similar payload capacity, and to compare the vehicles for differences in performance. The comparisons were made on the basis of the following performance relations: (a) speed-mean obstacle spacing, (b) minimum obstacle spacing required, (c) speed-obstacle clearance, and (d) steering angle-mean obstacle spacing.

4. An additional purpose was to develop a method of predicting the speed of a vehicle maneuvering in lateral obstacles.

Scope

5. Six vehicles were tested on a statistically designed, man-made lateral obstacle course. Each vehicle was tested at four obstacle spacings. Since there were limitations in time and funds for this program, efforts were concentrated on spacings below 20 ft* because they were believed to have a highly significant effect on vehicle performance. The tests and test course were designed such that the only terrain factor significantly affecting vehicle performance was obstacle spacing. Soil strength, visibility, slope, and stem size, all of which affect vehicle performance in a natural environment, were not considered in this study. A total of 118 tests were conducted. In 78 of these tests, instrumentation was used to measure vehicle responses such as steering angle, driveline torque, speed, and distance traveled.

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

PART II: FIELD TEST PROGRAM

Location and Description of Test Area

6. The area in which the lateral obstacle tests were conducted was a dry lake bed (alkali flat) located approximately 20 miles northeast of Carson City, Nevada (fig. 1). This lake bed has a barren, smooth, level (maximum slope of 0.02 percent), firm surface. The soil is a silt (ML) according to the Unified Soil Classification System.[3]

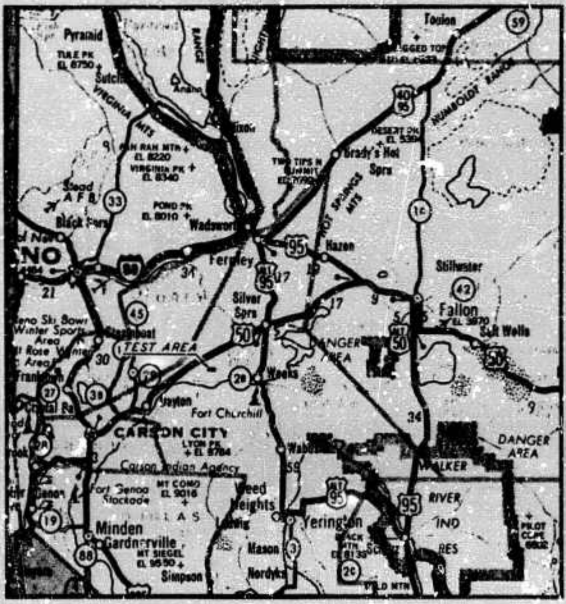


Fig. 1. Location of test area

Test Course Design and Construction

7. A driver maneuvering his vehicle through a natural stand of trees is confronted with several problems. First and most obvious is the need to maneuver around trees that are too large to override. Second, he may be confronted with other factors such as slope, soil strength, and visibility that will have varying degrees of effect on the ability of the vehicle to negotiate the forest. Taken singly, the effects of these natural deterrents on vehicle performance can be evaluated. But when one or more of the latter factors act in concert with trees to deter vehicle movement, it is difficult to isolate the effects of the separate factors. It is obvious that the most logical approach is to evaluate the performance relative to only one factor at a time, while holding constant as many of the other factors as possible. To attempt to locate these ideal single-factor conditions in nature, if they indeed exist, would be prohibitive both from the standpoint of time and expense. The obvious alternative is to build a test course in which it is possible to vary one factor while holding the others constant. Thus, the lateral obstacle course

designed for these tests was a first step in a system of controlling the causes to study the effects. As stated previously it represents but one variable--stem spacing.

8. While it is generally known that nature is not purely random in its placement of trees, research into detailed samples of natural forests reveals that a certain degree of randomness does exist. The lateral obstacle course was therefore designed using random numbers to define the x-y coordinates of the obstacle positions.

9. The size of the course was selected to provide an area large enough to give realistic results, yet small enough to be practical. This resulted in a course 300 ft wide by 500 ft long. Mean spacing values of 14, 16, 18, and 20 ft for the lateral obstacles were selected because from an earlier investigation it was hypothesized that these spacings would represent the spacing-dependency range of the six vehicles. Once the spacing values had been selected, it was then necessary to determine how many obstacles would be required (for the known area of 150,000 sq ft) to achieve each of the desired spacings. This was determined by using the structural cell[4] concept relation

$$S_m = 1.13 \sqrt{\frac{A}{N}}$$

where

S_m = mean spacing of stems, ft

A = total area, sq ft

N = number of stems contained within the area, A

Using the desired spacing values and the known area and solving for N resulted in the required number of stems per spacing as tabulated below:

Mean Spacing Desired, ft	No. of Stems Required
20	479
18	591
16	748
14	977

10. A random number generator on a GE-225 computer was then used to

obtain the required pairs of numbers to serve as x-y coordinates of the obstacles. A condition of this program was that every obstacle be at least 1 ft from its nearest neighbor. The x-y coordinates were converted to polar coordinates. Each obstacle was then assigned a number and an obstacle spacing color code. All information pertinent to each obstacle was placed on IBM punch cards. A sample card is shown in fig. 2. The

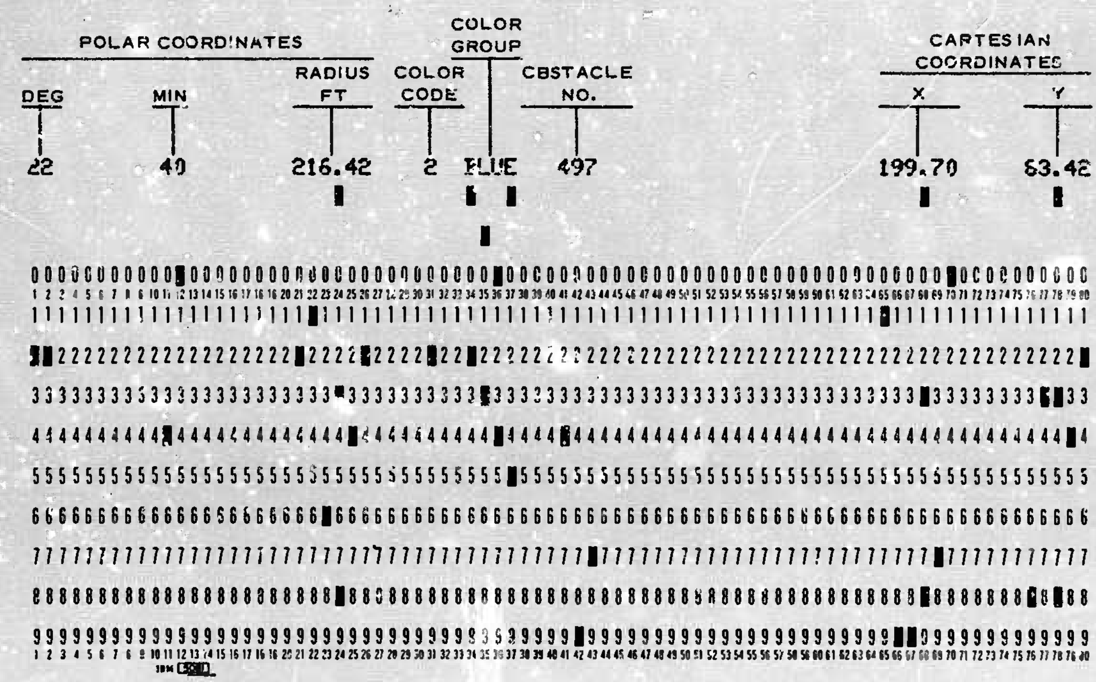


Fig. 2. Sample IBM data card

cards were then arranged in ascending order of polar angles, and printed sheets containing all necessary information from the cards were obtained from a high-speed printer. A sample of these sheets is shown in fig. 3. These sheets were then used together with a chain and a theodolite on one setup to establish the obstacle location in the field. Once the location was established, it was identified by a color-coded marker driven into the soil. The marker remained in place throughout the test program. Hence, obstacles could be removed or replaced at these locations to obtain any of the four spacings without the further aid of a theodolite or any measuring devices. Once the smallest spacing (all color groups combined) had been established, any of the other three spacings could be obtained by simply

POLAR COORDINATES			COLOR	COLOR	OBSTACLE	CARTESIAN COORDINATES	
DEG	MIN	RADIUS, FT	CODE	GROUP	NO.	X	Y
13	30	185.39	1	BLACK	7	180.27	43.29
13	52	250.51	1	BLACK	92	243.20	60.05
14	10	249.75	3	ORANGE	604	242.15	61.14
14	13	253.66	1	BLACK	17	245.88	62.34
14	42	167.71	1	BLACK	381	162.22	42.57
14	45	192.35	1	BLACK	423	185.99	49.02
14	58	232.92	1	BLACK	333	225.00	60.20
15	26	130.73	1	BLACK	105	126.00	34.82
15	49	188.01	3	ORANGE	654	180.89	51.26
15	57	271.70	1	BLACK	456	261.23	74.70
15	58	79.67	3	ORANGE	680	76.59	21.93
16	24	195.87	4	GREEN	888	187.89	55.33
16	31	258.72	1	BLACK	303	248.03	73.61
16	39	276.69	4	GREEN	916	265.08	79.31
16	52	166.35	3	ORANGE	705	159.19	48.29
17	3	312.61	1	BLACK	114	298.84	91.73
17	30	249.59	1	BLACK	232	238.02	75.10
17	30	291.58	3	ORANGE	714	278.07	87.71
17	51	308.63	1	BLACK	317	293.77	94.63
17	54	176.34	1	BLACK	417	167.80	54.22
18	20	293.04	4	GREEN	834	278.16	92.20
18	24	69.40	4	GREEN	761	65.84	21.92
18	35	306.14	2	BLUE	534	290.16	97.62
18	47	220.15	4	GREEN	773	208.42	70.91
18	51	171.03	3	ORANGE	594	161.85	55.27
18	58	226.04	1	BLACK	267	213.76	73.50
19	4	248.91	3	ORANGE	710	235.24	81.37
19	12	185.99	2	BLUE	565	175.56	61.14
19	35	178.01	1	BLACK	310	167.71	59.69
19	45	168.64	3	ORANGE	644	158.71	57.01
19	53	312.43	4	GREEN	759	293.78	106.32
20	1	53.35	2	BLUE	514	50.12	18.27
20	8	130.33	1	BLACK	448	122.36	44.89
20	38	269.37	1	BLACK	209	252.07	94.96
21	10	58.40	4	GREEN	866	54.46	21.09
21	20	147.80	4	GREEN	839	137.66	53.79
21	21	219.68	2	BLUE	581	204.60	80.01
21	46	116.31	1	BLACK	80	108.01	43.15
21	58	242.87	1	BLACK	240	225.24	90.86
22	3	308.25	2	BLUE	570	285.67	115.79
22	3	310.26	3	ORANGE	732	287.55	116.53
22	38	311.24	1	BLACK	137	287.25	119.82
22	40	216.42	2	BLUE	497	199.70	83.42
22	40	264.26	3	ORANGE	612	243.83	101.88
22	47	244.74	3	ORANGE	716	225.63	94.82
22	57	194.73	1	BLACK	347	179.29	75.98

Fig. 3. Sample computer printout of obstacle course data

removing obstacles of the color (or colors) not applicable to the desired spacing. A tabulation indicating application of each color group is shown below.

Desired Mean Spacing, ft	No. of Obstacles	Applicable Color Groups	Remove to Obtain Desired Spacing
14	977	Black, blue, orange, green	None
16	748	Black, blue, orange	Green

(Continued)

Desired Mean Spacing, ft	No. of Obstacles	Applicable Color Groups	Remove to Obtain Desired Spacing
18	591	Black, blue	Orange, green
20	479	Black	Blue, orange, green

A section of the established course is shown in fig. 4, and a typical obstacle used in the tests is shown in fig. 5. The obstacles were 2-in. by 2-in. by 8-ft wooden poles. One end of the pole was rounded to fit into a stand. The stand was anchored to the soil with large nails driven through holes in the base. An obstacle stand with anchoring nails and color-code marker is also shown in fig. 5. Plan views of the course showing the exact locations of the obstacles for the four mean spacings were plotted by an incremental on-line plotter connected with the GE-225 computer.

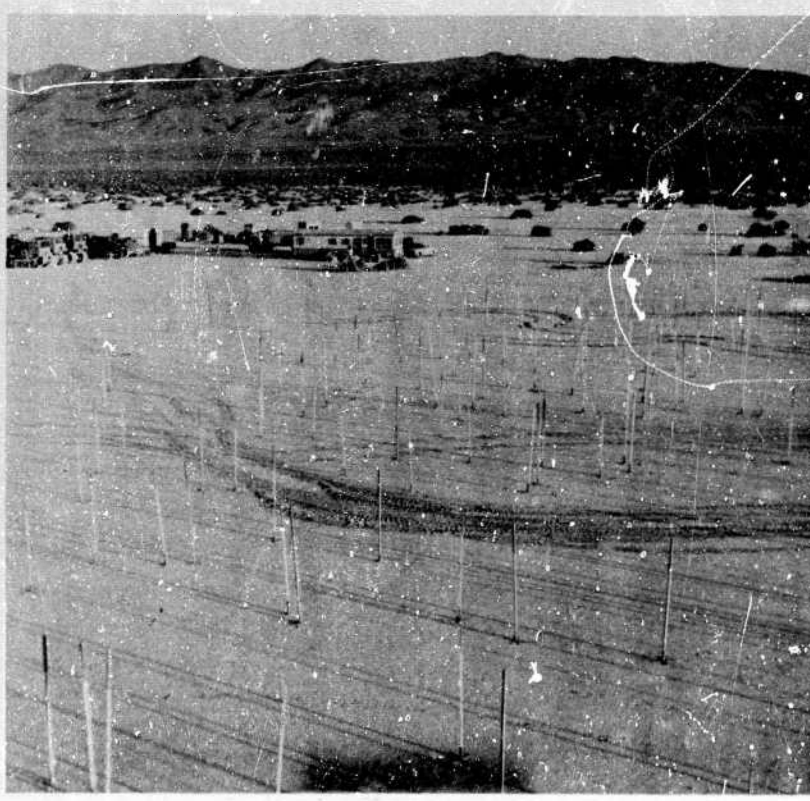


Fig. 4. Section of lateral obstacle course. Mean obstacle spacing 14 ft

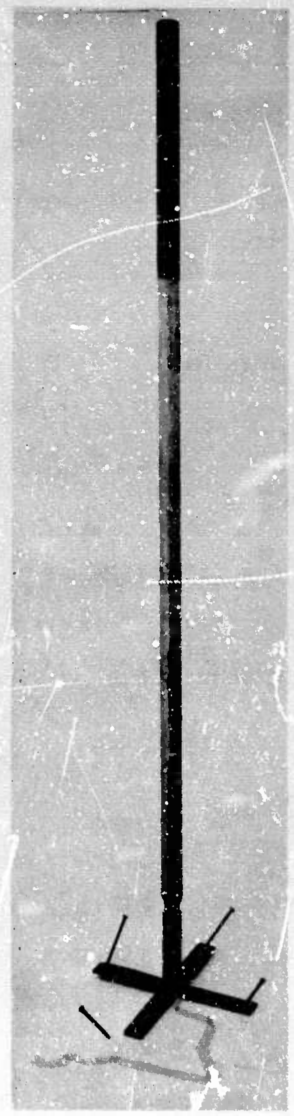


Fig. 5. Closeup of obstacle

Vehicles Tested

11. Three military vehicles and the three MEXA vehicles, all having approximately equal payloads, were tested on the lateral obstacle course. A summary of vehicle characteristics pertinent to this study is given below. A more detailed list of vehicle characteristics is given in Report 1 of this series.[5]

Designation	Width ft	Length ft	Payload lb	Total Wt, lb	Tire Pressure psi	Maximum Steering Rate deg/sec	Maximum Steering Angle deg
XM410E1 (8x8)	8.50	22.00	5000	16,504	20	7.2	22
M35A1 (6x6)	8.00	22.25	5000	18,225	35	8.9	26
M113 (full tracked)	8.83	16.75	4000	22,500	--	NA	NA
MEXA 10x10	9.58	28.00	5000	18,030	9	10.6	30
MEXA 8x8	8.42	32.00	5000	19,013	9	10.6	30
MEXA track	8.50	33.00	5000	19,680	--	10.6	30

The vehicles were tested at the respective weights shown above. The respective tire pressures listed above are the recommended cross-country pressures and were used throughout the lateral obstacle tests. The test vehicles are shown in figs. 6 and 7.

Instrumentation and Equipment

12. Instrumentation and test equipment are described in detail in Report 1 of this series.[5] Definitions of specialized terms used herein are also given.

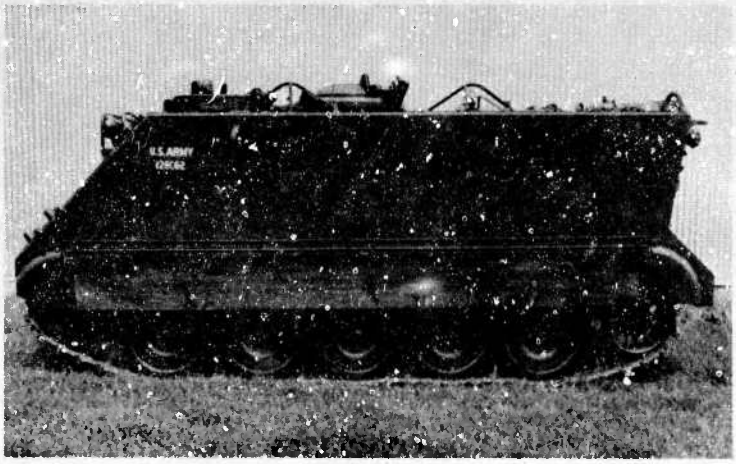
Data Acquisition

Vehicle performance measurements

13. The basic system used to record the various performance

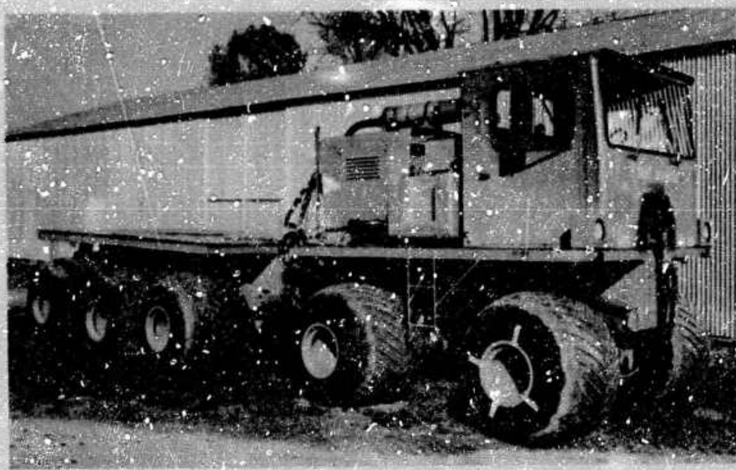
a. XM410E1

b. M35A1



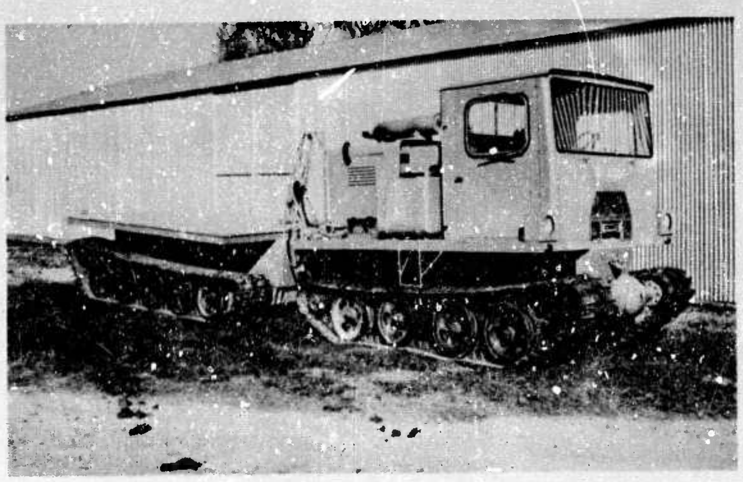
c. M113

Fig. 6. Military vehicles used in test program



a. MEXA 10x10

b. MEXA 8x8



c. MEXA track

Fig. 7. MEXA vehicles used in test program

parameters was a 36-channel, direct-print oscillograph and two 4-channel amplifier units. The entire system, together with an a-c power supply, was located on the bed of the vehicle being tested. A typical installation is shown in fig. 8. The following performance parameters

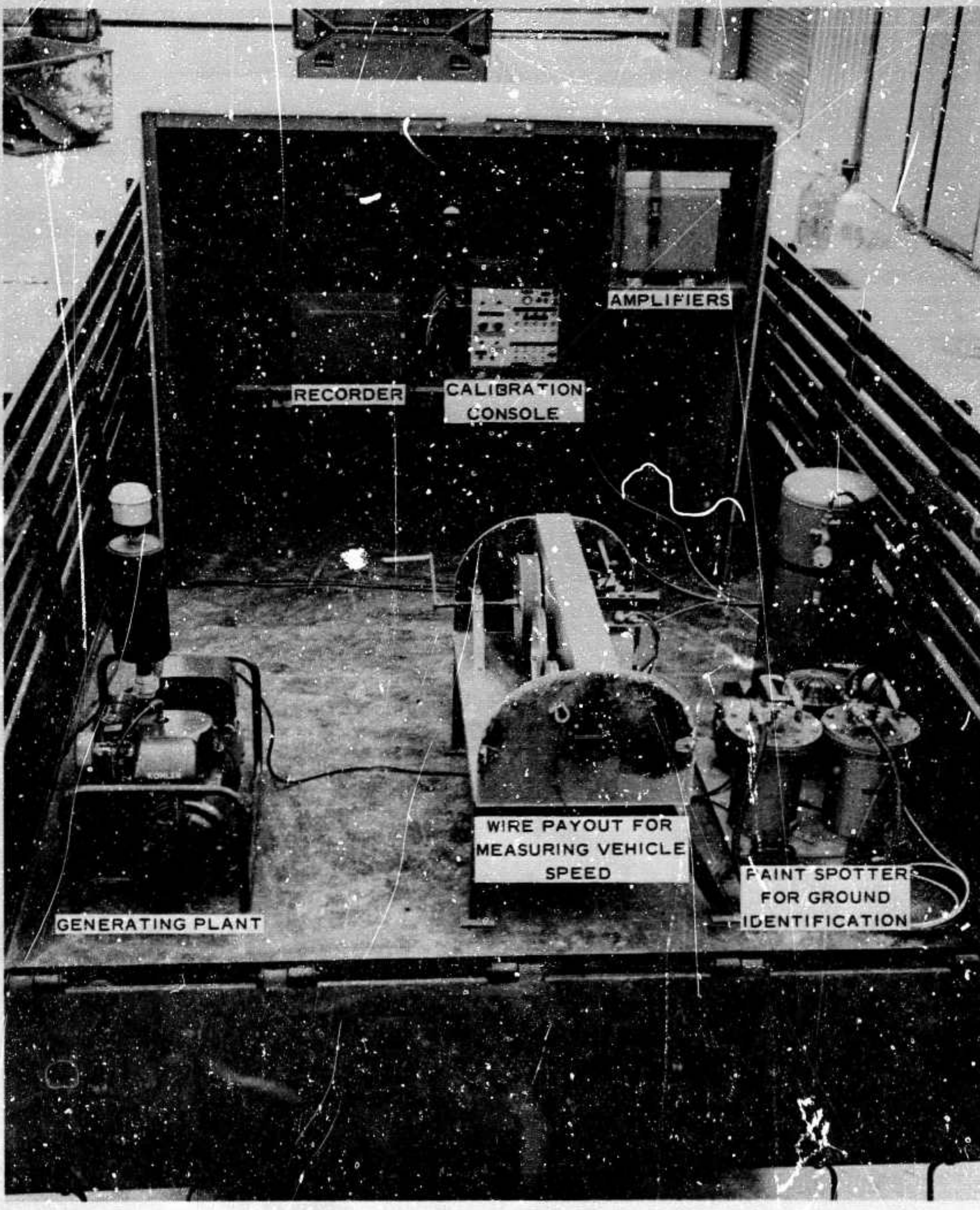


Fig. 8. Typical installation of instrumentation system in test vehicle

were measured and recorded in 78 tests:

- Distance traveled by vehicle
- Distance traveled by wheel or track
- Drive-line torque
- Steering angle
- Vehicle speed
- Wheel or track speed
- Time

Event marks were recorded on an oscillogram to identify pertinent ground positions of the vehicle during the test, such as entrance to and exit from the test course and contacts made with obstacles. The actual path of the vehicle was plotted on a plan view of the obstacle course after each test.

Soil data

14. As previously stated, the test site had a very firm soil surface, which virtually eliminated the effect of soil strength as a significant factor in vehicle performance. Consequently, a minimum number of soil strength measurements (in terms of cone index) were made to characterize the test site. The average cone index was 710 at the surface and 570+ at a depth of 1 in. During the test program measurements were made to ensure that the soil strength had not changed significantly due to traffic or weather conditions. These periodic checks revealed that neither the soil strength nor the surface conditions changed appreciably during the testing.

Photographic data

15. Full photographic coverage of the tests including 16mm movies, 35mm slides, 4x5 prints, and aerial photographs was obtained.

Tests Conducted and Test Procedures

Tests conducted

16. A total of 78 tests utilizing full instrumentation were conducted with the six vehicles at the four mean spacings of the obstacles

as tabulated below. A detailed summary of results is shown in table 1.

	No. of Tests Conducted by Vehicles						
Spacing ft	XM410	M35A1	M113	MEXA 10x10	MEXA 8x8	MEXA Track	Total
20	3	2	3	2	4	2	16
18	3	3	3	4	3	3	19
16	3	3	3	4	5	3	21
14	3	4	4	4	4	3	22
Total	12	12	13	14	16	11	78

Throughout the test program, it became necessary to make vehicle repairs. Periodically these repairs caused a temporary halt in the testing sequence. During these periods, 40 check tests were conducted with other vehicles in which only elapsed time was measured by a stopwatch. The check test data are also shown in table 1.

Test procedures

17. The vehicle was positioned approximately 250 ft from the test course perimeter, and all instrument calibrations were recorded. The driver was instructed to accelerate outside the course to the speed that he thought he would be able to maintain inside the course without contacting any obstacles. The only restraint placed upon the driver's path through the obstacles was that he exit the course from the side opposite that which he entered. This was to prevent the driver from entering one "end" of the course and exiting at one "side" of the course. An event mark was recorded on the oscillogram upon entrance of the course and again upon exit in each test. If during a test, the vehicle struck an obstacle, moved in reverse, or was halted for any reason, an appropriate event mark was recorded on the oscillogram. Each vehicle maneuvered through each obstacle spacing arrangement at least twice. Generally, three tests were conducted at each spacing along the length of the test course. A few tests were also conducted across the width of the course (the 300-ft dimension) to determine if the course was possibly "directional" relative to the results obtained. An observer rode in the cab of the vehicles on every test and compiled his observations at the conclusion of each test.

Stopwatch times and notes were taken on each test by ground observers. At the conclusion of each test the path of the left wheel of the vehicle was plotted. Each test was initiated at a different entrance point on the course so that the driver would not follow in tire or track marks remaining from previous tests. Graphic plan views of the actual vehicle paths are shown in plates 1-24.

18. A few special tests in which different vehicles followed the same path through the course were conducted to make a direct comparison of speed performance.

PART III: ANALYSIS

19. Analysis of the data collected during these tests was primarily directed to obtaining the following performance relations: (a) speed-mean obstacle spacing, (b) minimum obstacle spacing required to maneuver, (c) speed-obstacle clearance, and (d) steering angle-mean obstacle spacing. For this study, speed is in terms of "speed made good," which is defined as the straight-line distance from the point at which the vehicle entered the course to the point at which the vehicle exited the course divided by the elapsed time. Mean spacing was determined during the design of the test course as discussed in paragraph 10.

20. The analysis consists of a critical examination and discussion of test results, the development of a technique for predicting speed-obstacle spacing relations on firm level surfaces (from the current test data), an extension of this technique to soft soils and sloping surfaces (from previous test data), and a comparison of predicted versus actual results.

Test Results

Vehicle-obstacle spacing relations

21. The values of speed made good shown in table 1 indicate that, with a few exceptions, there was only a slight deviation in the results of three or four tests of a given vehicle at a given spacing. In instances where the deviations were large, the vehicle usually came so close to an obstacle that it had to be halted or nearly halted to permit the removal of the metal obstacle stand in order to prevent a tire puncture. The curves presented in plates 25 and 26 are drawn through values of the average speed made good at each spacing. The speeds measured during the check tests were used in determining the average speed made good. A summary plot of the speed-spacing relations for all vehicles is shown in plate 27.

22. Effect of vehicle width. Analysis of the data curves (plates 25 and 26) indicates that each curve has a distinct intercept on the mean obstacle spacing axis. Previous tests in lateral obstacles have indicated

that this intercept is mainly related to a vehicle's width. In the current tests the zero-speed intercepts of the speed-spacing relations ranged from 1.41 to 1.59 times the vehicle width or an average of 1.5 times the vehicle width (1.5W). Results of the Mississippi tests indicated an average intercept of 1.44 times the vehicle width.[1] From a practical standpoint, a simple relation exists between the minimum spacing required by a vehicle to maneuver and the width of the vehicle because as obstacle spacing approaches vehicle width, speed will rapidly approach zero. For a vehicle maneuvering at some spacing slightly greater than its width, its speed will generally be less than 1 mph. The MEXA 10x10 has a width of 9.6 ft, and a minimum spacing for this vehicle based on the factor of 1.5W would be 14.4 ft. Results of the tests show a two-run average of 0.9 mph for the MEXA 10x10 at the 14-ft spacing. At such very low speeds, the power available to the vehicle cannot be fully utilized and hence is not a factor. The length of the vehicle does not become a factor of appreciable magnitude because the rear wheels will track the front wheels much closer at the lower speeds than at the higher speeds. Certainly there is a length-to-width ratio above which vehicle length would also influence minimum spacing; however, most current military vehicles have a ratio such that width is the dominant vehicle dimension. The tabulation below is a comparison of 1.5W and the intercept values as determined from plates 25 and 26:

Vehicle	Width (W) ft	1.5W ft	Intercept ft	Intercept/W	Difference* %
XM410E1	8.50	12.7	12.0	1.41	+5.5
M35A1	8.00	12.0	12.3	1.54	-2.5
M113	8.83	13.2	12.4	1.40	+6.0
MEXA 10x10	9.58	14.4	13.6	1.42	+5.5
MEXA 8x8	8.42	12.6	12.5	1.48	+0.8
MEXA Track	8.50	12.7	13.5	1.59	-6.3

* Percent difference was calculated as follows: $\frac{1.5W - \text{Intercept}}{1.5W} \times 100$.

23. Effects of steering type. A study of the summary plot (plate 27) reveals three rather distinct groups of the vehicle performance curves;

they are the M35A1 and XM410E1, the M113, and the three MEXA vehicles. An attempt to analyze the cause of this grouping indicates that several characteristics of the vehicles may be contributing to the arrangement of the curves. One characteristic believed to be contributing to this grouping is steering type. It is interesting to note from plate 27 that the two fastest vehicles, the XM410E1 and M35A1, have Ackerman steering systems. The M113 has a skid steer system, and the slowest vehicles, the MEXA vehicles, have articulated steering systems. This is considered significant, but certainly is not conclusive due to a lack of sufficient data to evaluate the effects of steering type.

24. Effects of vehicle acceleration. A second major vehicle characteristic believed to be contributing to the grouping of the curves is the vehicle's ability to accelerate.

25. Data obtained during hard-surface acceleration tests (plate 28) reveal the same general grouping of vehicle performance as that shown in plate 27. These acceleration tests were conducted on a paved, level surface with no obstacles present, as part of the test program phase dealing with the performance of the vehicles on various soil strengths.[6] Plate 28 presents the speed-time curves for the vehicles as an indication of their relative acceleration abilities. The slope of any finite portion of a vehicle's speed-time curve is the acceleration of the vehicle for the corresponding finite time interval. Because the slope is continually changing (acceleration is not constant), a single numerical descriptor for each vehicle could not be determined to describe the grouping of the speed-obstacle spacing curves. However, the similarity of groupings tends to confirm the assumption that the acceleration characteristics of a vehicle are indeed significant in determining a vehicle's speed while maneuvering in lateral obstacles on a hard surface.

26. Acceleration characteristics of a vehicle are related to the tractive force it can develop. This suggests that the maximum tractive force developed by each vehicle could give an indication of the relative positions of the speed-obstacle spacing curves. Examination of the speed-obstacle spacing curves (plate 27) indicates that the lower portion of each curve appears to be nearly linear. It was found that the speed value

at the upper end of this linear portion of the curves approximated the vehicle speed occurring at 25 percent of the hard-surface maximum tractive force. It was also determined that the straight-line portion of the speed-obstacle spacing curves terminated at approximately 2.0 times the vehicle width (fig. 9). The point defined by these two coordinates (25 percent maximum tractive force and 2.0 times vehicle width) is believed to define the point on the speed-obstacle spacing relation above which vehicle speed is no longer highly dependent upon obstacle spacing, i.e. an inflection point on the speed-obstacle spacing curve.

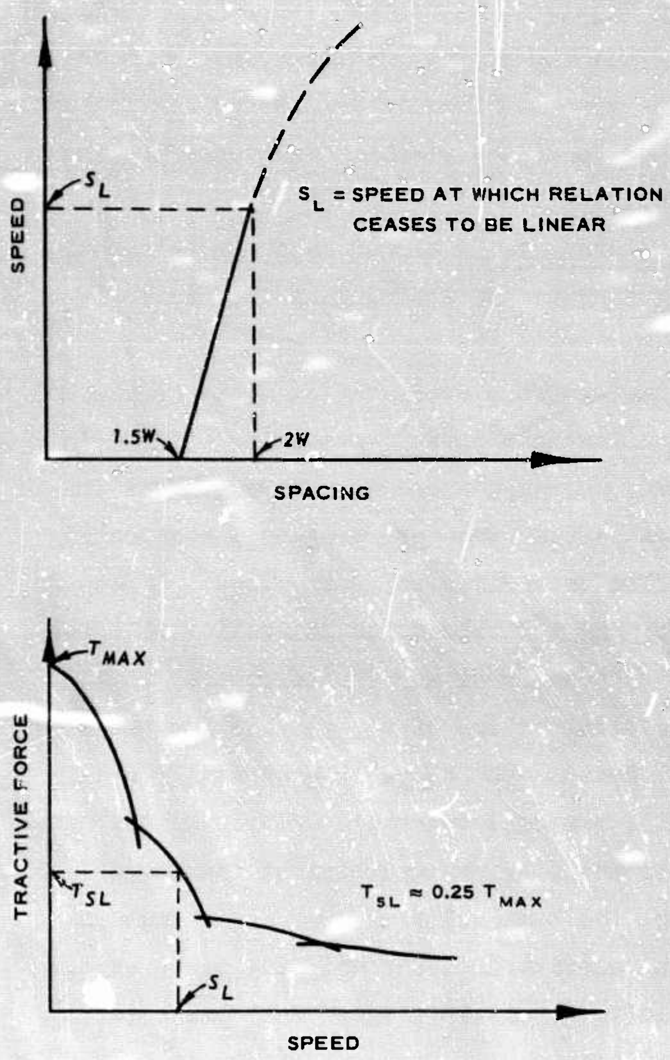


Fig. 9. Traction-speed-spacing analysis

Speed-obstacle
clearance relations

27. Measurements were made of the distance from an obstacle along the vehicle's path to the left side of the vehicle in an attempt to establish a relation between speed made good and obstacle clearance for the four obstacle spacings and the six vehicles tested. Observations made during the testing, along with measurements taken from the vehicle traverses, indicate that the closest clearances exist on the left side of the vehicle. This is not surprising when it is considered that the driver has a better view of the left side of the vehicle than of the right side. The clearances (see table 2) plotted in plate 29 are the clearances from the

left or driver's side. Inspection of the plot reveals no definite trend of clearance with speed or spacing. Although not shown in the plot, a separate study indicated that vehicle characteristics per se did not appear to be significant. Thus, the clearance is fairly constant at 2.5 ft for the six vehicles tested during this program, regardless of speed, vehicle, width, or obstacle spacing.

28. A study of notes made during testing sheds some light on the fact that the clearance requirement of a driver-vehicle system is fairly constant. In maneuvering through a field of obstacles, the driver must select his path as far ahead as possible. Once the driver has selected a path requiring him to pass between two obstacles, he must then judge the distance between these obstacles relative to the width of his vehicle. Once he has made this evaluation, he then classifies his further progress into one of two basic categories: a difficult passage or an easy passage. After making this classification, the driver then decides whether he will be able to negotiate the selected path at a speed equal to, greater than, or less than his present speed. Should the driver decide that the maneuver will be an easy passage, he then becomes less concerned with the width of the vehicle and concentrates on continuing on as straight a path and at as high a speed as possible. However, even in an easy passage it appears that the driver will stay as close as possible to the obstacle on his left (approximately 2.5 ft). Should the driver determine that his passage between two obstacles will be difficult, he then becomes more concerned with the width of his vehicle than with maintaining a straight-line course. The driver will then slow down and maneuver his vehicle, attempting to orient his path 90 deg to a line between the obstacles. Once in this position, the driver will again pass between the obstacles, staying as close as possible to the obstacle on his left (again approximately 2.5 ft). Obviously, the driver will, at times, pass between obstacles that will not allow him to attain a clearance of 2.5 ft. However, this condition is usually an exception. In selecting his path the driver will scan the array of obstacles confronting him and make his selection such that a majority of the time he will provide himself with a clearance of approximately 2.5 ft. More specifically, the driver will try to select a path

that contains a majority of easy passages and a minority of difficult passages. Only when no alternative exists will the driver negotiate the difficult passage, and by his own selection this would occur relatively few times. This then appears to be an inherent safety factor that the driver desires, and possibly a better term for the clearance might be "desired clearance" rather than "required clearance."

29. The possibility exists that the desired clearance, as determined, could be mainly driver dependent. However, results of repeated tests at the four spacings indicate that the tests were conducted at a maximum speed, and therefore the data are believed to be indicative of a performance at maximum conditions, and consequently less dependent upon driver variability.

Steering angle-mean obstacle spacing relations

30. The data obtained from steering transducers installed on each vehicle were analyzed in an attempt to relate the steering characteristics or capabilities of the vehicles to the mean spacing of the obstacles. Initially, an attempt was made to relate the maximum steering angle utilized by the vehicle to the obstacle spacings. This did not result in any meaningful relation because at least once during every test each vehicle used the maximum steering capability available. From the continuous records of steering response available for 78 tests, the actual steering angles used by a vehicle in maneuvering around each obstacle adjacent to its path were measured. These data were then grouped into 5-deg "bands" up to the maximum steering capability of each vehicle. No steering angles were measured on the M113 due to the difficulty of instrumenting a skid-steer-type vehicle to monitor continuous changes in steering angle. The average number of occurrences for each vehicle (except the M113) at each spacing is shown in table 3. A frequency-distribution graph was then made for each vehicle at the four obstacle spacings. These graphs are shown in plates 30 and 31. Inspection of the graphs reveals that as the obstacle spacing increases, there is a general decrease in the utilization of the maximum steering angle range. One point worth noting is that the vehicles used their maximum steering angles only a small percentage of the

time, even at the 14-ft spacing, which approaches the minimum spacing required by each vehicle. Equally significant is the large utilization of the steering angles falling in the smaller ranges, i.e. 0 to 10 deg. Generally, each vehicle utilized steering angles in the range from 0 deg to approximately 40 percent of the maximum angle a majority of the time.

31. A weighted average of the steering angles was obtained for each spacing of the obstacles; these data are plotted in plate 32. Inspection of these plots reveals the same grouping relative to performance as that indicated in the plots of speed-obstacle clearance shown in plate 27.

32. It is to be noted that the average steering angle utilized by each vehicle, with one exception, does not vary more than 3 deg from the 14-ft spacing to the 20-ft spacing. The exception to this is the MEXA 10x10 vehicle, which has a variation of 5 deg. It is also to be noted that the MEXA vehicles consistently utilized larger steering angles than did the conventional military vehicles. It should be emphasized that the spacing variation of 14 to 20 ft represents a range extending from near the minimum requirement to the point at which speed is no longer dependent mainly upon obstacle spacing.

Prediction of Vehicle-Obstacle Relations

33. A technique for predicting speed-obstacle spacing relations on firm, level soil was developed on the assumption that the actual speed-obstacle spacing relation could be approximated by a straight line (paragraph 26). The procedure for defining this predicted relation, as well as procedures for considering the effects of softer soils and slopes, is described in the following paragraphs.

34. The technique will be presented in two parts: first a speed-obstacle spacing relation will be predicted that represents the maximum speed that a vehicle can travel while maneuvering through lateral obstacles on a firm surface; second, the prediction technique will be extended to include the consideration of the effects of soft soils and terrain slope on vehicle speed. As an aid to the presentation of the technique, the M35A1 will be used in an example.

Speed-obstacle spacing
relation on a firm surface

35. Prediction of the speed-obstacle spacing relation is accomplished by determining two end point values and connecting them with a straight line. One of the two values is a minimum spacing value (intercept with the spacing axis or x-axis of an obstacle spacing-vehicle speed relation) determined by 1.5 times vehicle width (paragraph 22), and the other value, maximum spacing value, is determined empirically (paragraph 26) as the upper speed limit for which obstacle spacing is the predominant controlling factor.

36. To predict the maximum spacing value in the speed-spacing relation, results from the analysis of the test data were used. It has been pointed out (paragraph 26) that the speed-spacing performance relations were linear up to a point of inflection where the speed corresponded to approximately 25 percent of maximum traction available to the vehicle on a hard surface. It was also determined empirically that this inflection point corresponded to approximately twice the vehicle width. Thus, these two coordinates were accepted as defining the upper limit for the predicted speed-spacing relation. The predicted relation is established as a straight line between the predicted minimum spacing value on the abscissa (1.5W) and the point position defining 2W and the maximum speed determined for 25 percent of maximum traction on a hard surface. Fig. 10 shows an example of a predicted speed-spacing relation for the M35A1.

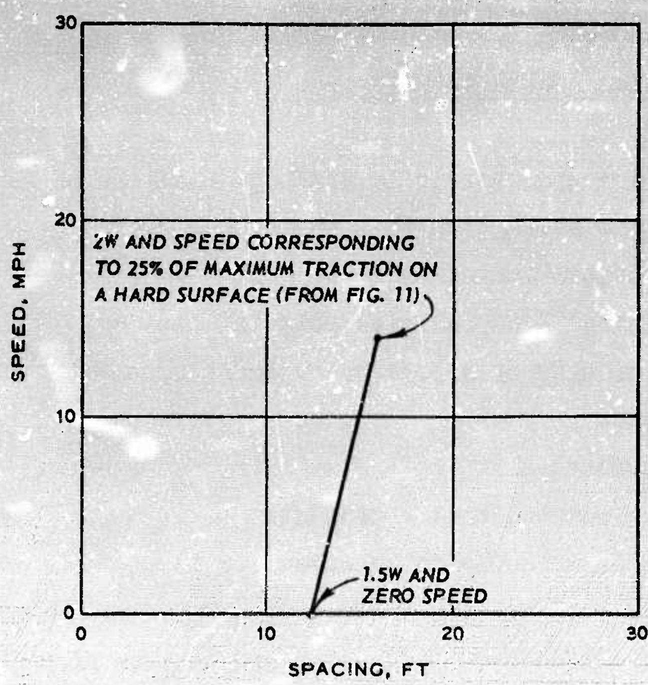


Fig. 10. Predicted speed-obstacle spacing relation for M35A1

Forces related to maneuvering on a firm surface

37. In any empirically

determined maximum performance relation of speed-obstacle spacing on a firm surface, there are inherent limitations imposed by (a) the vehicle's mechanical and physical characteristics, (b) the driver's responses, (c) the strength of the traction medium, and (d) the obstacle spacing. The extent to which these factors were considered in predicting the speed-obstacle spacing relation for a firm, level surface (fig. 10) was explained in paragraphs 35 and 36. In order to extend the prediction methods to environments characterized by soft soils and slopes it is necessary to define the relation of certain forces to the maximum performance in lateral obstacles on a firm, level surface. These forces are identified as (a) available tractive force, (b) motion resistance, and (c) force required to maneuver.

38. <u>Available tractive force.</u> The tractive force available on a firm, level surface is represented by a maximum performance relation of tractive force-speed. The maximum performance relation for the M35A1 is shown in fig. 11. The relation represents the maximum tractive force the M35A1 can develop from a speed slightly greater than zero to its maximum

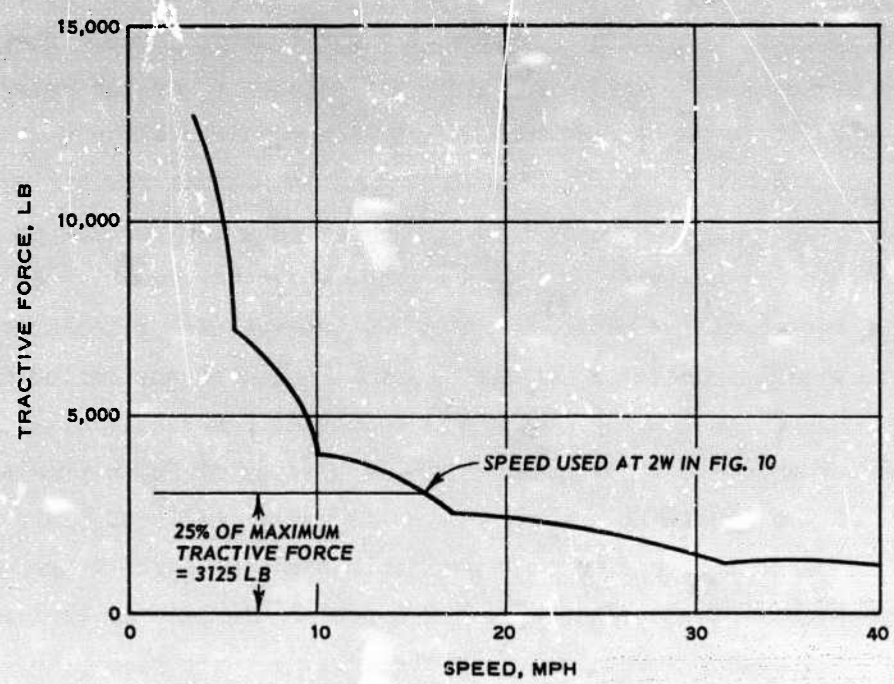


Fig. 11. Maximum performance curve for
M35A1 on a firm surface

speed. The inflections in the curve indicate optimum speeds for gear changes. The performance range included for each gear is the torque-rpm range, assuming no wheel slip, at which the torque output is at a maximum for each speed.

39. Motion resistance. Resistance to motion (rolling resistance) is at a minimum on a level, smooth firm surface, thus allowing maximum vehicle speeds to be achieved for either maneuvering or traveling in a straight line.

40. Force required to maneuver. To ensure that there is sufficient traction available to permit the vehicle to accelerate between obstacles after slowing down to avoid an obstacle, a reserve force for accelerating is added to all the other forces resisting the vehicle during maneuvering. From the tests reported herein to establish speed-obstacle spacing relations, it was found that a vehicle cannot maneuver in obstacle spacings less than 1.5W and that the need to maneuver diminishes rapidly at obstacle spacings greater than approximately 2W, approaching zero when maneuvering is no longer required. At obstacle spacings just above 1.5W, the vehicle has a large reserve force available for accelerating, but the small spacing restricts the utilization of this reserve force. That is, the period of acceleration is limited by the necessity for the driver to slow to a speed that will allow him enough time to execute the next maneuver required to avoid the next obstacle. This means that for the gear selected a driver will be operating his vehicle in a low torque-rpm range not included in the maximum performance curve shown in fig. 11. At the point where the obstacle spacing becomes 2W, the vehicle performance in terms of torque-rpm reaches a maximum toward the end of any period of acceleration during maneuvering in lateral obstacles. For this optimum or maximum performance condition occurring at a spacing of 2W, approximately 25 percent of the available tractive force is being utilized. This point of 2W and 25 percent of the maximum available tractive force represents a tradeoff point beyond which the speed of a vehicle in lateral obstacles is limited to a much greater extent by the vehicle power plant than by obstacle spacing.

41. Based on the preceding discussion it is possible to approximate

the first part of a relation for the force required to maneuver and obstacle spacing as illustrated in fig. 12. The hard-surface motion resistance is subtracted from the 25 percent maximum tractive force value so that the relation will represent only that force required to maneuver.

42. In order to complete the relation shown in fig. 12 it was necessary to establish the obstacle spacing at which maneuvering is no longer required and the force required to maneuver becomes zero. The test data reported herein indicate that for a given vehicle, there is a relation between obstacle spacing and the number of maneuvers required to negotiate obstacles at the fastest possible speed. Data for the M35A1 are tabulated below. These data are plotted in fig. 13 to determine the obstacle spacing at which no maneuvers would be required. The intercept on the spacing axis of the curve in fig. 13

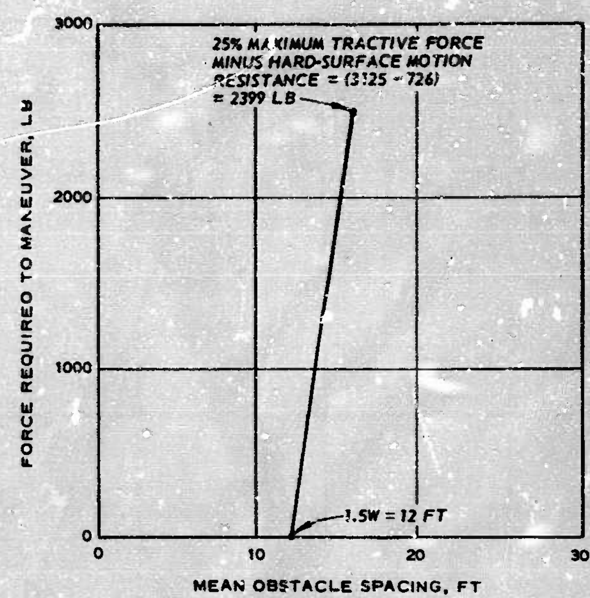


Fig. 12. First stage in development of force required to maneuver-mean obstacle spacing relation for M35A1

Obstacle Spacing ft	No. of Maneuvers
14	211
16	62
18	31
20	23

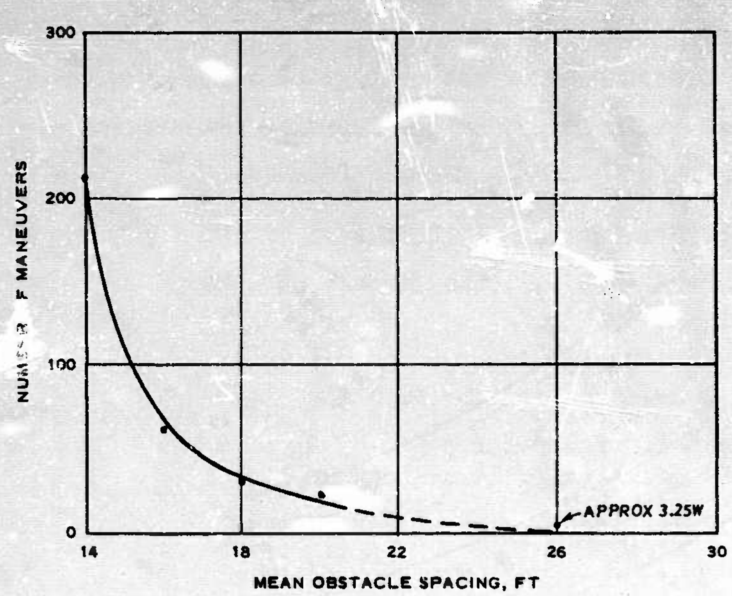


Fig. 13. Determination of obstacle spacing at which M35A1 is no longer required to maneuver

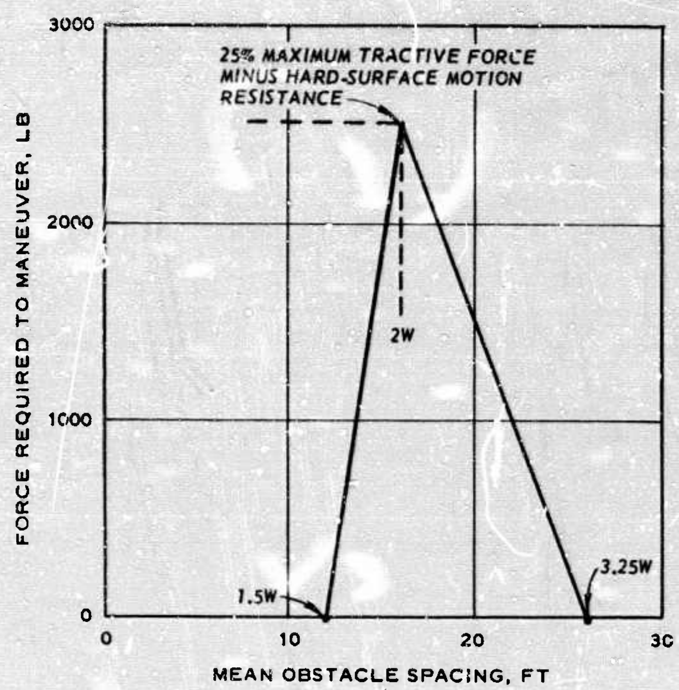


Fig. 14. Force required to maneuver-mean obstacle spacing relation (final) for M35A1

represents the point at which the vehicle would no longer need to maneuver, and would consequently require no reserve force for maneuvering. As indicated on the curve, this spacing is approximately 3.25 times the width (8 ft) of the M35A1.

43. By locating the point 3.25W on the abcissa of fig. 12 and assuming a linear relation also exists for the second portion of the relation, the final form of fig. 12 is illustrated in fig. 14.

Prediction considering force requirements for maneuvering on a level, smooth, firm surface

44. To illustrate the procedures for predicting the speed of a vehicle considering only the resisting forces (S_f) related to maneuvering on a level, smooth, firm surface, the following example is used.

Given: Mean obstacle spacing = 15 ft

Motion resistance of firm surface on M35A1 = 726 lb*

Force required to maneuver F_m in 15-ft mean spacing = 1850 lb (from fig. 14)

Maximum performance curve for M35A1 on a firm surface (fig. 11 redrawn as fig. 15)

Find: Speed as limited by resisting forces

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* This value is obtained by measuring the force required to tow the M35A1 at a slow, uniform speed on the surface in question.

Solution: Add 726 lb and 1850 lb to give a total resisting force F_t of 2576 lb. Read the corresponding speed S_f = 16.5 mph in fig. 15

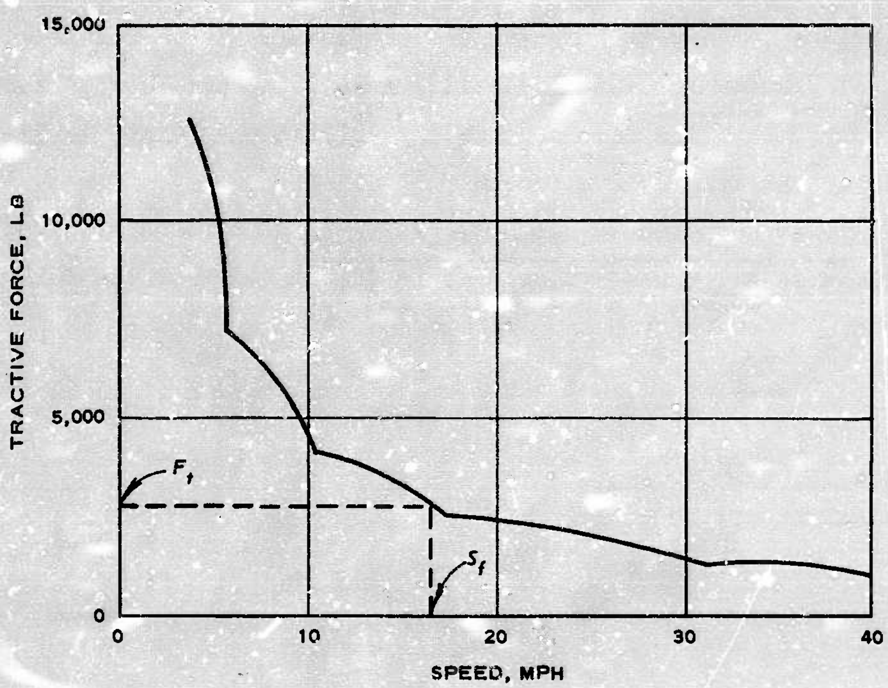

Fig. 15. Maximum performance curve for M35A1 on a firm surface illustrating determination of S_f

The predicted speed considering only the resisting forces S_f (16.5 mph) is compared with the speed predicted by considering only obstacle spacing S_o (10.0 mph, obtained from fig. 10), and the lower of the two speeds is selected as the predicted average speed.

Soil strength and terrain slope

45. The speed-obstacle spacing relation described in the preceding paragraphs applies to a vehicle operating on a firm surface and gives no consideration to the possibility that the forces imposed by some terrain conditions could limit a vehicle's performance to a lower speed. In actual practice, a vehicle is frequently required to overcome resisting forces imposed by soft soils and terrain slopes. The magnitudes of these resisting forces must be determined so that their effects on vehicle speed can be accounted for in making a speed prediction. Determination of resisting

forces caused by soil and slope is discussed in the following paragraphs.

46. Force required to overcome soil resistance (R_s). The force required to overcome the motion resistance of a soil R_s of a given strength is usually determined by measurement. Should a measured value not be available, the motion resistance can usually be approximated by examination of previously acquired data. These data would be the results of tests conducted with the same or similar vehicles on similar soils having approximately the same soil strength.

47. Force required to climb slopes (F_s). The force required to climb a slope is a computed value. It is determined from the following equation

$$F_s = W \sin \theta \tag{1}$$

where

W = weight of the vehicle, lb

θ = slope angle, deg

The slope angle is usually measured or determined from available terrain information.

Prediction considering resisting forces related to maneuvering on a sloping sand surface

48. The techniques used to predict the amount of degradation in speed caused by the resisting forces related to slopes, soft soils, and maneuvering are similar to those discussed in paragraph 44. A summation of the forces determined for maneuvering F_m (fig. 14), climbing slopes F_s (paragraph 47), and overcoming motion resistance of the soil R_s (paragraph 46) will give the total resisting force F_t with which to determine the vehicle speed. The total resisting force is expressed mathematically as follows

$$F_t = F_m + F_s + R_s \tag{2}$$

The speed determination is accomplished by utilizing the tractive force-speed performance curve for the vehicle and soil conditions in question.

To illustrate, the performance curve for a firm surface and a dry to moist sand shown in fig. 16 will be used to predict a speed for the M35A1, using

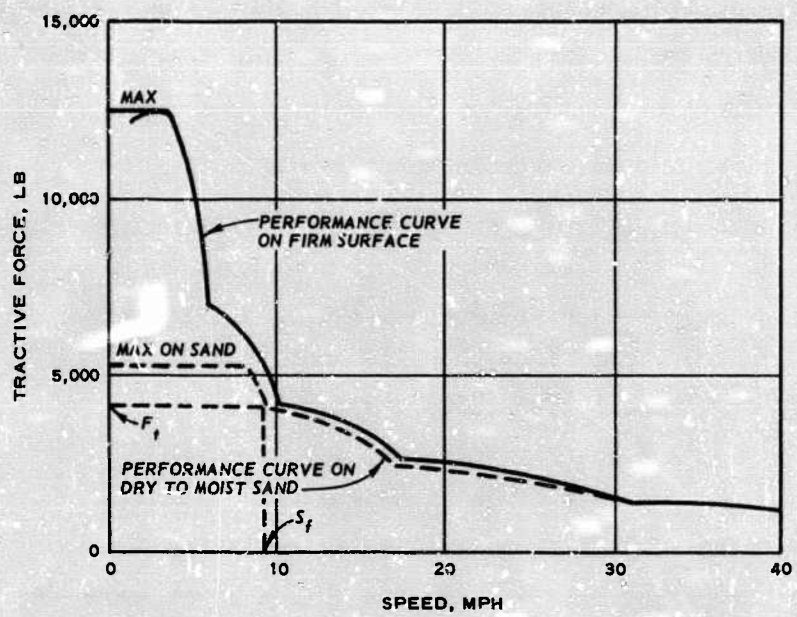

Fig. 16. Maximum performance curves for M35A1 operating on a firm surface and on a sand surface

terrain data measured during the Mississippi tests[1] to determine the resisting force.

49. The performance curve for the sand was obtained by using the field-measured drawbar pull-slip relation. The motion resistance measured during the testing (1362 lb) was added to the drawbar pull values to obtain a tractive force-slip relation for the sand as shown in fig. 17. The sand performance curve (broken line in fig. 16) is determined by reducing the speeds shown on the

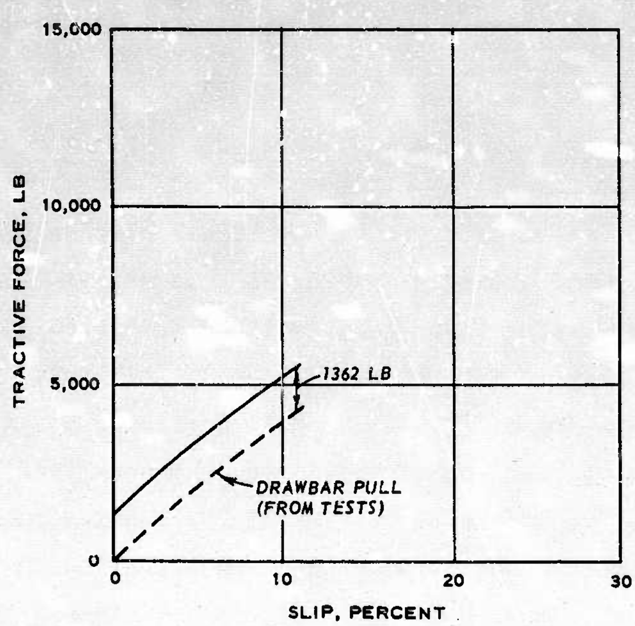

Fig. 17. Tractive force-slip relation for M35A1 on sand

firm-surface performance curve by appropriate slip values according to the tractive force-slip relation.

50. The following example is given to illustrate the procedures for predicting the speed of a vehicle considering only the resisting forces related to maneuvering on a sloping surface.

Given: Mean obstacle spacing = 16.4 ft

F_m = 2380 lb (from fig. 14)

θ = 1.35 deg

$F_s = W \sin \theta$ = 426 lb

Soil strength = 150 cone index

Soil type (USCS), sand (SP)

Moisture condition, dry to moist

R_s = 1362 lb (measured)

Find: Speed as controlled by resisting forces

Solution: By substituting the values given above for F_m, F_s, and R_s into equation 2, F_t is computed to be 4168 lb

Enter 4168 lb on the ordinate of fig. 16 and project the point horizontally to intersect the performance curve, then vertically downward to intersect the abscissa to determine the predicted speed S_f of 9.3 mph

Speed predicted as the minimum of S_o and S_f

51. To predict the final average speed, the average speed allowed by the obstacle spacing S_o as well as the average speed allowed by the resisting forces S_f must be predicted, and the smaller of S_o and S_f selected for the final speed prediction. For example, for the obstacle spacing of 16.4 ft used in paragraph 50, a speed of 9.3 mph was determined for S_f, considering the total resisting forces imposed by the terrain conditions. Using the spacing value of 16.4 ft and entering the speed-obstacle spacing curve (fig. 10) an average speed of 15 mph was determined for S_o. S_o is the highest average speed possible if the resisting forces are low enough to allow the vehicle to achieve an average speed of 15 mph or higher. However, the speed as determined by considering

the resisting forces was 9.3 mph; and the vehicle would be limited to this lower speed prior to achieving any speed that would be limited by obstacle spacing. The predicted average speed would then be the lesser of the two speeds, S_o and S_f, or 9.3 mph.

52. The following example is presented to illustrate the procedures for determining the final average speed prediction considering the total resisting forces F_t, at different soil strengths, and obstacle spacing on a separate basis.

Given: Mean obstacle spacing = 13.9 ft

θ = 5.6 deg

F_m = 1250 lb

F_s = 1778 lb

The following soil strengths and their corresponding measured values for motion resistance

Sand Soil Strength CI	R_s lb
150	1362
67	2062
48	3500

Find: The predicted average speeds considering F_t and obstacle spacing separately for each soil strength

Solution: By using prediction procedures described in paragraphs 45-51 the following average speed predictions were made for S_o and S_f and are presented in the following tabulation with other pertinent data.

Mean Obstacle Spacing ft	Soil Strength CI	Resisting Force, lb F_m	F_s	R_s	F_t	Speed mph S_f	S_o
13.9	150	1250	1778	1362	4390	9.4	6.8
13.9	67	1250	1778	2062	5090	8.6	6.8
13.9	48	1250	1778	3500	6528	0.0	6.8

The predicted speed values in the tabulation on the preceding page for soil strengths 150 CI and 67 CI indicate sufficient traction can be developed to overcome the total resisting forces and the average speed would be limited by the obstacle spacing. However, at a soil strength of 48 CI the available tractive force would not be sufficient to overcome the resisting forces and sustain a speed of 6.8 mph. Consequently, the resisting forces would limit the speed of the vehicle to some value less than 6.8 mph and the obstacle spacing would no longer control the vehicle's performance.

53. It is believed that for moderate slope conditions and obstacle spacings of 1.5W to 2W the obstacle spacings will limit speed until the soil strength approaches the minimum strength on which the vehicle can travel. Obviously, for a given soil strength and obstacle spacing, the resisting forces could limit vehicle speed when the slope approaches the maximum gradeability of the vehicle.

Comparison of Actual and Predicted Results

54. Using the techniques outlined in the previous paragraphs (45-51) predictions were made for the three military vehicles and the three MEXA vehicles on the firm surface at the Nevada test site. Predictions were also made using available soil strength and slope data for seven tests conducted with the M35A1 in the Mississippi test program.[1] The use of speed-obstacle spacing predictions as input data for the WES analytical model is described in Appendix A.

Nevada tests

55. Using the prediction techniques presented in paragraphs 44 and 51, predictions were made for the six vehicles. Speed-obstacle spacing relations were predicted, and these predictions were compared with measured speeds. These comparisons are presented in plates 33 and 34. Inspection of the plates shows that the predicted relations are not the best straight-line fits to the actual data; however, they approximate the actual data to an acceptable degree of accuracy. It is noted that better agreement could be obtained in most cases by retaining the slopes of the predicted relations, but shifting their positions slightly to the left or right. This

suggests that the criterion 1.5W for establishing the minimum spacing could possibly be improved.

Mississippi tests

56. Using the prediction techniques presented in paragraphs 48-51, predictions were made for seven tests conducted with the M35A1 in the Mississippi test program for which soil and slope data were available. These predictions were compared with the measured test speeds and are presented in the following tabulation.

Mean Obstacle Spacing ft	Resisting Force, lb				Speed, mph		
	F_m	R_s	F_s	F_t	S_o	S_f	Actual*
12.3	200	1362	1859	3421	1.5**	14.2	4.3
13.9†	1250	1362	1800	4412	6.8**	9.4	4.6
15.7	2300	1362	542	4204	13.0	9.6**	7.4
16.4†	2380	1362	426	4168	15.0	9.7**	12.6
16.1	2500	1362	1433	5295	13.9	8.5**	8.1
14.3	1500	1348	--	2848	7.6**	16.0	6.3
14.8	1750	1348	--	3098	9.5**	15.5	8.3

* Speed measured during tests.
** Predicted speed.
† Used as examples in illustrating prediction techniques.

The speeds listed above are plotted in fig. 18 as a comparison of actual versus predicted values. The percent accuracies of the predicted values are as follows:

Speed, mph		Accuracy
Actual	Predicted	%
4.3	1.5	35
4.6	6.8	67
7.4	9.6	77
12.6	9.7	77
8.1	8.5	95
6.3	7.6	83
8.3	9.5	87

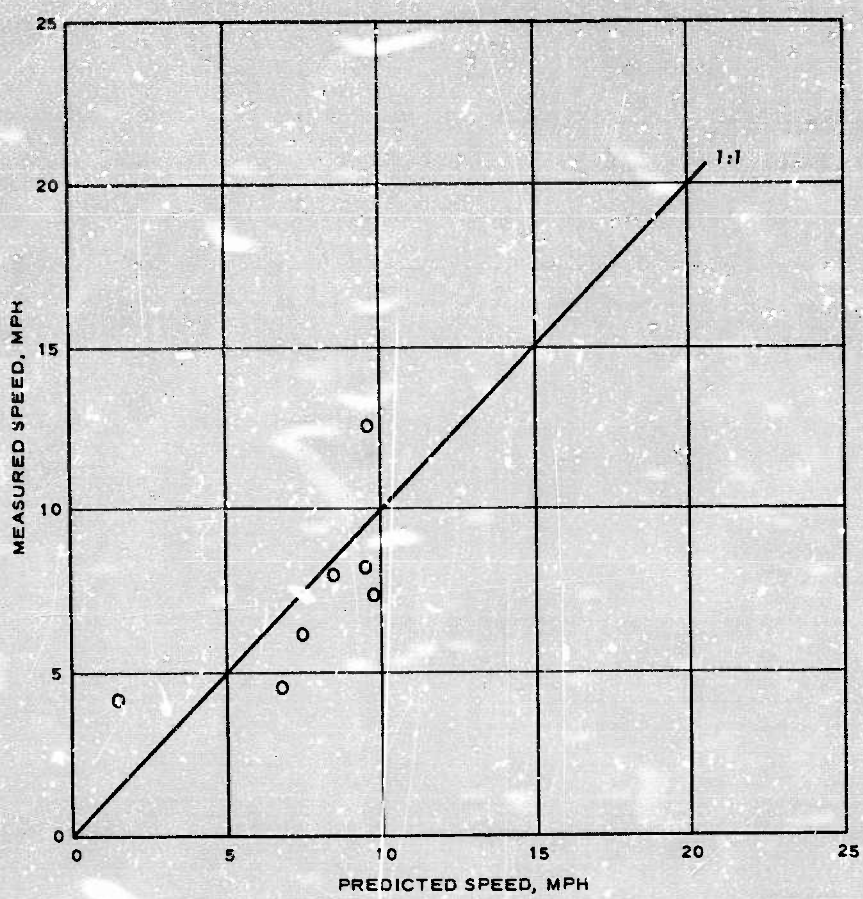

Fig. 18. Predicted and actual speeds, M35A1

While the accuracy is not as high as might be desired in all cases, it is believed to be acceptable when considering the relatively small amount of data presently available relating vehicle performance to lateral obstacle problems.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

57. As a result of the analysis of the data herein, the following conclusions are believed to be evident:

- a. The conventional military vehicles exhibited better performance than the MEXA vehicles when maneuvering in lateral obstacles on a hard surface (plate 27).
- b. The minimum required spacing for a vehicle maneuvering in lateral obstacles is approximately equal to 1.5 times the vehicle width (paragraph 22).
- c. The range of obstacle spacings affecting vehicle speed lies generally within the limits of 1.5 to 2.0 times the vehicle width (paragraph 36).
- d. The speed-obstacle spacing relation for any given vehicle appears to have a definite slope. This slope is indicative of both the acceleration capabilities and steering characteristics of the vehicle (paragraphs 26 and 30).
- e. The slope of the speed-obstacle spacing relation can be defined by assuming a linear relation from a speed of zero at 1.5 times the vehicle width to a speed representing 25 percent of the maximum tractive force at 2.0 times the vehicle width (paragraph 26).
- f. The clearance on the left side desired by a driver maneuvering a vehicle in lateral obstacles appears to be approximately 2.5 ft (paragraph 27).
- g. The steering angle utilized by a vehicle when maneuvering through obstacles having spacing values from 1.5 to 2.0 times the vehicle width falls within a range of 0 to 15 deg a majority of the time, and for only a very small percentage of time was the maximum steering angle utilized (paragraph 30).
- h. The technique for predicting the speed-mean obstacle spacing relation yielded a reasonable prediction accuracy when applied to data not used in the development of the technique (paragraph 56).

Recommendations

58. As a result of the tests conducted, the analysis of data, and the conclusions reached, the following recommendations are made:

a. Tests should be conducted in which obstacle spacings greater than 20 ft and less than 14 ft would be used, i.e. smaller spacing values to better establish the minimum required spacing and larger spacing values to better establish the point at which vehicle speed is no longer dependent upon obstacle spacing.

b. Tests should be conducted in which the complete range of obstacle spacings is utilized on varying soil strengths. This would determine the soil strength at which the MEXA vehicles may exhibit better performance than the conventional vehicles while maneuvering in lateral obstacles.

c. Once soil strength-obstacle spacing-vehicle performance relations have been defined, it is recommended that tests be conducted in which stem size and visibility are considered separately.

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4. Mills, H. L., "Quantitative Physiognomic Analysis of the Vegetation of the Florida Everglades," Contract Report No. 3-72, 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss; prepared by Marshall University, Huntington, W. Va.

5. U. S. Army Engineer Waterways Experiment Station, CE, "Mobility Exercise A (MEXA) Field Test Program; Report 1, Summary," (in preparation), Vicksburg, Miss.

6. Schreiner, B. G., "Mobility Exercise A (MEXA) Field Test Program; Report 2, Soft-Soil Performance of MEXA Test Beds," (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1

Summary of Test Results

Vehicle	Mean Obstacle Spacing ft	Test No.	Direction of Vehicle Travel	Reference	Elapsed Time sec	Path Distance ft	Average Speed mph	Speed Made Good mph	Average Speed Made Good mph	Remarks	Check Test Data Speed Made Good, mph
XM410E1	14	OB-21-1	North	Plate 1	29	501	11.1	11.8		Completed test; brushed four obstacles, knocked three down	--
		OB-21-2	North		118	535	3.1	3.0	6.6	Completed test; brushed three obstacles, knocked one down	
		OB-21-3	South		67	553	5.6	[illegible].2		Completed test; brushed two obstacles	
	16	OB-22-1	South	Plate 2	26	523	13.9	13.4		Completed test; no obstacles contacted	--
		OB-22-2	North		25	510	13.7	13.7	13.4	Completed test; no obstacles contacted	
		OB-22-3	North		26	595	15.3	13.1		Completed test; brushed one obstacle	
	18	OB-23-1	North	Plate 3	18	510	19.5	19.2		Completed test; one obstacle knocked down	--
		OB-23-2	North		19	512	18.0	17.7	17.8	No obstacles contacted	
		OB-23-3	South		21	505	16.6	16.6		Completed test; one obstacle knocked down	
	20	OB-24-1	North	Plate 4	14	506	24.0	23.4		Completed test; no obstacles contacted	--
		OB-24-2	North		17	520	20.2	19.7	22.8	Completed test; no obstacles contacted	
		OB-24-3	South		13	501	25.3	25.4		Completed test; no obstacles contacted	
M35A1	14	OB-4-1	North	Plate 5	75	553	5.0	4.5		Completed test; no obstacles contacted	--
		OB-4-2	North		62	559	6.1	5.6	4.8	Completed test; brushed one obstacle	
		OB-4-3	North		58	526	6.2	6.0		Completed test; no obstacles contacted	
		OB-4-4	South		109	550	3.4	3.1		Completed test; brushed two obstacles, one reversal	
	16	OB-7-1	North	Plate 6	25	515	14.1	13.8		Completed test; no obstacles contacted	15.9, 18.7, 15.8, 16.3
		OB-7-2	North		26	541	14.4	13.5	15.1	Completed test; no obstacles contacted	
		OB-7-3	South		29	533	12.5	12.1		Completed test; brushed one obstacle	
	18	OB-14-1	North	Plate 7	21	503	16.5	16.5		Completed test; no obstacles contacted	--
		OB-14-2	South		18	514	19.1	19.2	18.7	Completed test; no obstacles contacted	
		OB-14-3	West		11	311	20.0	20.4		Completed test; no obstacles contacted	
	20	OB-17-1	North	Plate 8	16	518	22.1	21.4	22.3	Completed test; no obstacles contacted	22.7, 22.4
		OB-17-2	South		15	501	22.8	22.9		Completed test; no obstacles contacted	
M113	14	OB-5-1	North	Plate 9	40	550	9.4	8.5		Completed test; one obstacle knocked down with rear corner of vehicle during pivot maneuver	--
		OB-5-2	North		119	554	3.2	3.0	5.3	Completed test; one obstacle knocked down by rear corner of vehicle; one reversal	
		OB-5-3	South		185	632	2.3	1.9*		Completed test; brushed two obstacles	
		OB-5-4	North		43	524	8.3	8.0		Completed test; no obstacles contacted	
	16	OB-6-1	North	Plate 10	35	533	10.4	9.9		Completed test; no obstacles contacted	10.7, 9.4, 11.7
		OB-6-2	North		32	514	10.9	10.6	10.6	Completed test; no obstacles contacted	
		OB-6-3	South		31	540	11.9	11.4		Completed test; no obstacles contacted	
	18	OB-15-1	North	Plate 11	27	526	13.0	12.5		Completed test; no obstacles contacted	13.1, 13.2, 13.0, 13.0
		OB-15-2	South		24	501	14.4	14.5	13.1	Completed test; brushed one obstacle	
		OB-15-3	East		16	325	13.5	12.5		Completed test; no obstacles contacted	
	20	OB-16-1	North	Plate 12	22	513	15.8	15.5		Completed test; no obstacles contacted	14.8, 15.2
		OB-16-2	South		21	501	16.4	16.6	15.5	Completed test; no obstacles contacted	
		OB-16-3	West		14	321	15.2	15.2		Completed test; no obstacles contacted	

(Continued)

* Required reversal.

Table 1 (Concluded)

Vehicle	Mean Obstacle Spacing ft	Test No.	Direction of Vehicle Travel	Reference	Elapsed Time sec	Path Distance ft	Average Speed mph	Speed Made Good mph	Average Speed Made Good mph	Remarks	Check Test Data Speed Made Good, mph
MEXA 10x10	14	OB-1-1	North	Plate 13	260	582	1.5	1.3	0.9	Completed test; brushed one obstacle	--
		OB-1-2	North		--	--	--	--		Became immobilized	
		OB-1-3	North		--	--	--	--		Became immobilized	
		OB-1-4	South		663	641	0.7	0.5		Completed test; brushed two obstacles	
	16	OB-9-1	North	Plate 14	99	538	3.7	3.4	2.6	Completed test; no obstacles contacted	3.6, 3.2, 2.3, 2.3
		OB-9-2	North		178	587	2.5	2.1		Completed test; brushed three obstacles, made two reversals	
		OB-9-3	South		215	561	1.8	1.6		Completed test; brushed three obstacles	
		OB-9-4	East		--	--	--	--		Completed test; no obstacles contacted	
	18	OB-12-1	South	Plate 15	57	518	6.8	6.0	5.2	Completed test; no obstacles contacted	5.7, 4.5, 4.5
		OB-12-2	South		70	525	5.1	4.9		Completed test; brushed one obstacle	
		OB-12-3	North		69	524	5.2	4.9		Completed test; brushed one obstacle	
		OB-12-4	East		37	347	6.3	5.9		Completed test; no obstacles contacted	
	20	OB-20-1	North	Plate 16	50	542	7.3	7.1	6.4	Completed test; no obstacles contacted	6.3, 6.0
		OB-20-2	South		56	504	6.1	6.1		Completed test; no obstacles contacted	
MEXA 8x8	14	OB-3-1	North	Plate 17	139	550	2.7	2.5	2.0	Completed test; no obstacles contacted	--
		OB-3-2	South		314	549	1.8	1.6		Completed test; no obstacles contacted	
		OB-3-3	South		135	560	2.8	2.7		Completed test; brushed one obstacle	
		OB-3-4	South		312	598	1.3	1.1		Completed test; brushed two obstacles	
	16	OB-10-1	North	Plate 18	64	523	5.5	5.3	4.6	Completed test; no obstacles contacted	4.1, 5.1, 4.6, 4.0
		OB-10-2	North		81	522	4.4	4.3		Completed test; no obstacles contacted	
		OB-10-3	South		115	620	3.7	3.4		Completed test; no obstacles contacted	
		OB-10-4	East		42	305	5.0	6.1		Completed test; no obstacles contacted; same path as test OB-9-4	
		OB-10-5	West		--	--	--	--		Completed test; no obstacles contacted	
	18	OB-11-1	South	Plate 19	53	533	6.8	6.7	6.2	Completed test; no obstacles contacted	5.9, 6.1
		OB-11-2	South		53	504	6.5	6.4		Completed test; no obstacles contacted	
		OB-11-3	East		35	310	6.1	6.1		Completed test; no obstacles contacted	
	20	OB-18-1	North	Plate 20	45	522	8.0	7.6	7.2	Completed test; no obstacles contacted	7.1, 6.5, 7.7, 8.0
		OB-18-2	South		64	501	5.4	5.4		Completed test; no obstacles contacted	
		OB-18-3	North		138	520	2.6	2.5**		Completed test; one obstacle knocked down, became temporarily immobilized	
		OB-18-4	South		27	501	12.5	12.6		Completed test; no obstacles contacted	
MEXA track	14	OB-2-1	North	Plate 21	93	552	4.1	3.7	1.6	Completed test; brushed two obstacles	--
		OB-2-2	North		217	576	0.9	0.9		Completed test; no obstacles contacted, one reversal	
		OB-2-3	North		652	560	0.6	0.5		Completed test; brushed two obstacles, became temporarily immobilized	
	16	OB-8-1	North	Plate 22	--	--	--	--	3.6	Completed test; no obstacles contacted	4.1
		OB-8-2	North		92	561	4.1	3.7		Completed test; one obstacle hit; one reversal	
		OB-8-3	South		115	563	3.3	3.1		Completed test; brushed two obstacles	
	18	OB-13-1	North	Plate 23	68	532	5.3	5.1	6.4	Completed test; no obstacles contacted	6.4, 6.3, 6.0
		OB-13-2	South		57	524	6.3	6.2		Completed test; no obstacles contacted	
		OB-13-3	East		24	302	8.7	8.6		Completed test; no obstacles contacted	
	20	OB-19-1	North	Plate 24	29	517	12.1	11.7	9.7	Completed test; no obstacles contacted	8.4, 10.9
		OB-19-2	South		43	502	8.0	8.0		Completed test; no obstacles contacted	

** Hit obstacle; required removal to continue.

Table 2

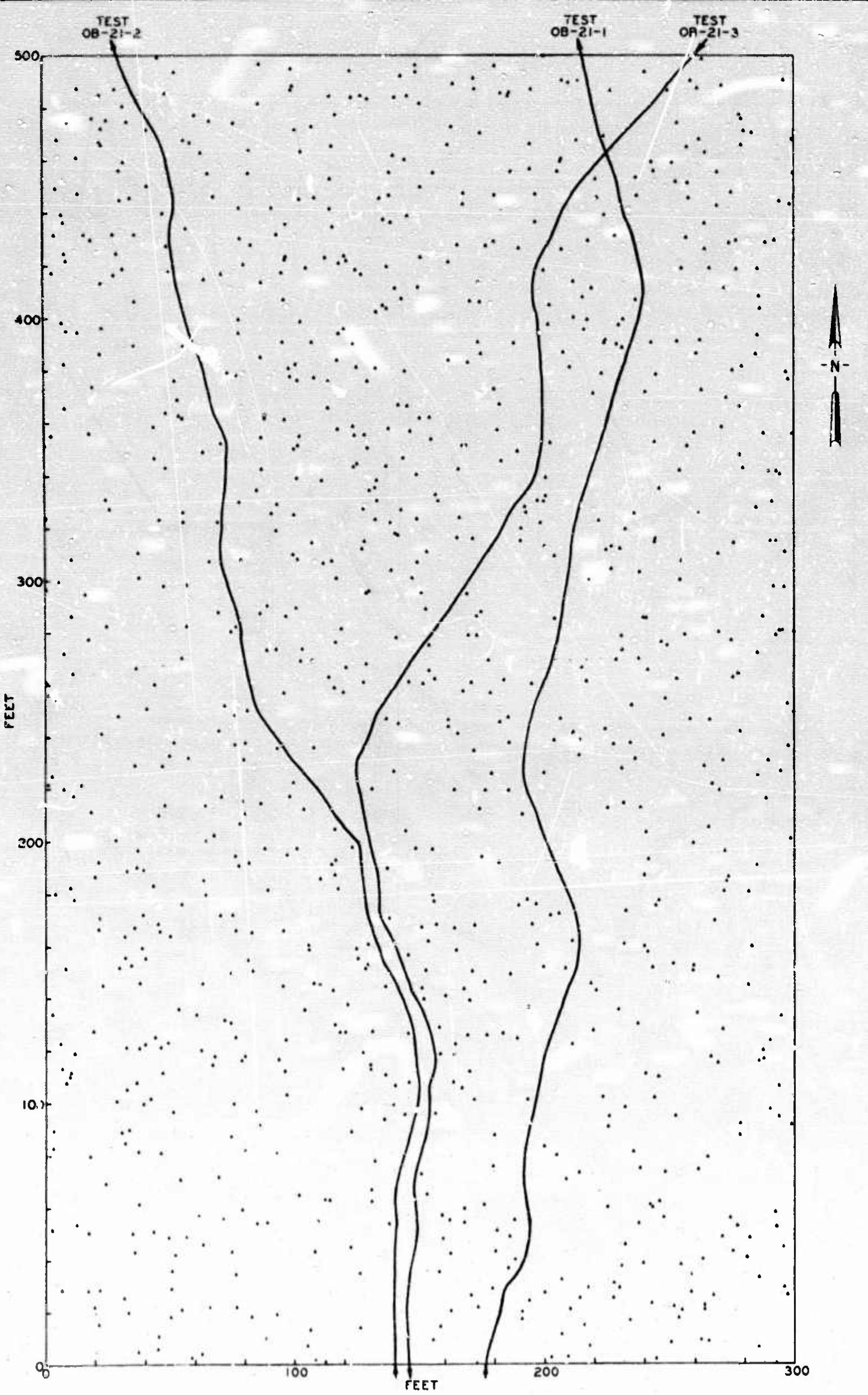
Summary of Clearance Data

Vehicle	Mean Obstacle Spacing ft	Test No.	Left Side Average Clearance ft
XM410E1	14	OB-21-1	2.5
		OB-21-2	2.1
		OB-21-3	2.5
	16	OB-22-1	2.7
		OB-22-2	2.5
		OB-22-3	2.7
	18	OB-23-1	2.6
		OB-23-2	2.8
		OB-23-3	2.8
	20	OB-24-1	2.6
		OB-24-2	2.8
		OB-24-3	2.8
M35A1	14	OB-4-1	--
		OB-4-2	2.3
		OB-4-3	2.6
		OB-4-4	2.0
	16	OB-7-1	1.9
		OB-7-2	2.9
		OB-7-3	2.4
	18	OB-14-1	2.2
		OB-14-2	2.6
		OB-14-3	3.1
	20	OB-17-1	3.0
		OB-17-2	2.6
M113	14	OB-5-1	--
		OB-5-2	2.9
		OB-5-3	3.0
		OB-5-4	3.2
	16	OB-6-1	3.6
		OB-6-2	3.1
		OB-6-3	2.9
	18	OB-15-1	2.8
		OB-15-2	3.1
		OB-15-3	3.8
	20	OB-16-1	2.9
		OB-16-2	3.0
		OB-16-3	2.5
MEXA 10x10	14	OB-1-1	2.5
		OB-1-2	--
		OB-1-3	--
		OB-1-4	2.2
	16	OB-9-1	2.9
		OB-9-2	2.3
		OB-9-3	2.7
	18	OB-12-1	2.3
		OB-12-2	2.0
		OB-12-3	1.9
		OB-12-4	1.7
	20	OB-20-1	2.3
		OB-20-2	2.5
MEXA 8x8	14	OB-3-1	--
		OB-3-2	2.6
		OB-3-3	2.1
		OB-3-4	2.3
	16	OB-10-1	2.5
		OB-10-2	2.1
		OB-10-3	2.0
		OB-10-4	2.3
	18	OB-11-1	2.3
		OB-11-2	2.7
		OB-11-3	2.9
	20	OB-18-1	2.3
		OB-18-2	2.4
		OB-18-3	2.4
		OB-18-4	2.4
MEXA track	14	OB-2-1	2.2
		OB-2-2	2.2
		OB-2-3	2.2
	16	OB-8-1	2.4
		OB-8-2	2.4
		OB-8-3	2.7
	18	OB-13-1	2.3
		OB-13-2	2.7
		OB-13-3	--
	20	OB-19-1	2.8
		OB-19-2	2.2

Table 3

Steering Angle Occurrences

Vehicle	Mean Obstacle Spacing ft	Occurrences per Steering Angle Class						Total
		0-5	5-10	10-15	15-20	20-25	25-30	
XM410E1	14	71	22	13	0	0	--	106
	16	37	9	2	0	0	--	48
	18	27	5	0	0	0	--	32
	20	23	2	0	0	0	--	25
M35A1	14	111	42	29	18	7	4	211
	16	31	19	3	7	2	0	62
	18	17	8	3	3	0	0	31
	20	17	4	1	1	0	0	23
MEXA 10x10	14	32	48	46	37	29	17	209
	16	35	51	51	30	28	13	208
	18	35	48	22	13	3	4	125
	20	29	11	6	9	6	0	61
MEXA 8x8	14	63	117	96	72	59	17	424
	16	47	48	30	26	10	10	171
	18	35	30	11	9	5	1	91
	20	56	56	24	23	9	5	173
MEXA track	14	94	97	91	57	38	21	398
	16	39	36	23	13	16	5	132
	18	26	37	11	5	3	2	84
	20	17	22	18	3	3	0	63

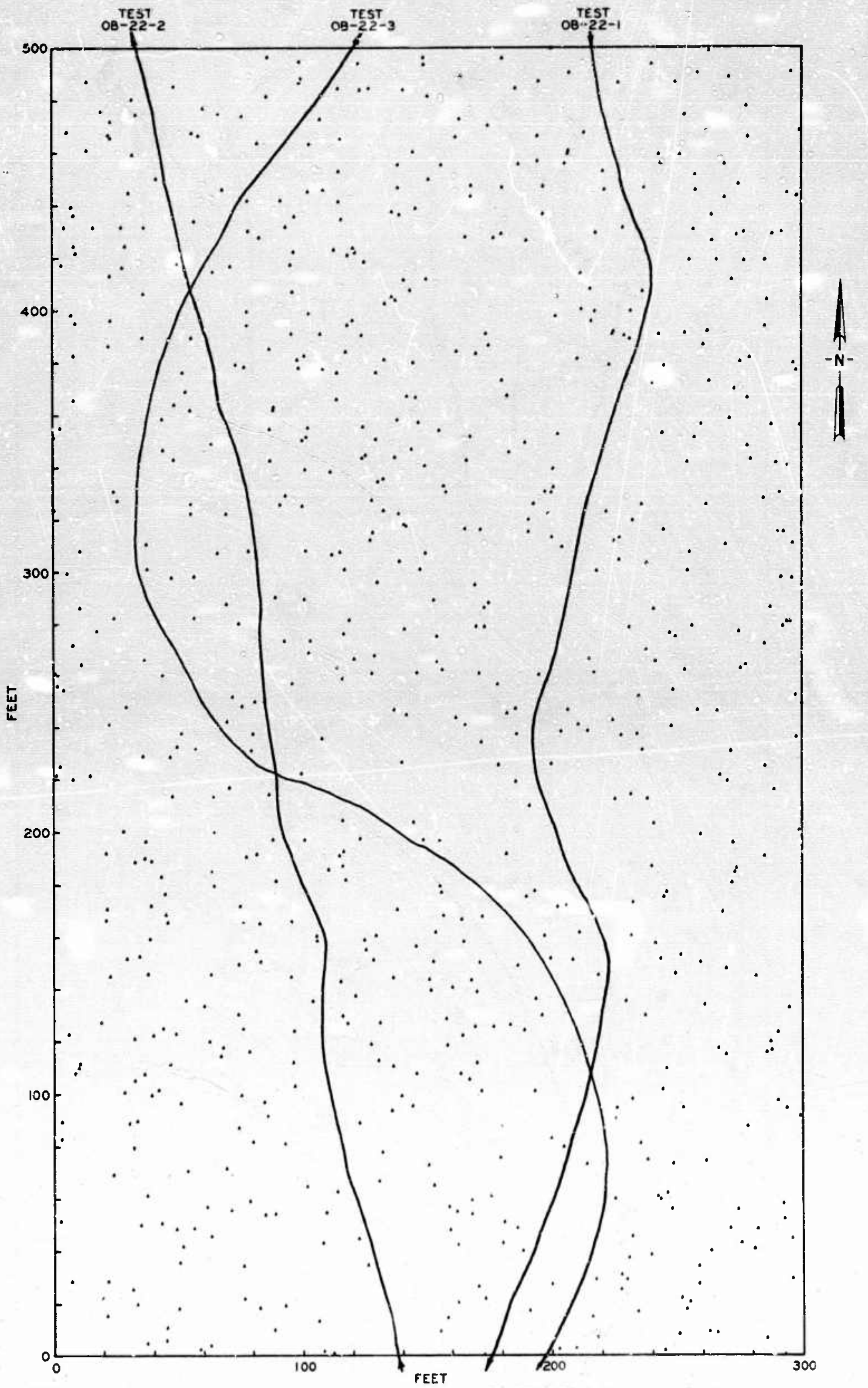


NOTE PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

PATHS OF XM410E1 THROUGH LATERAL OBSTACLE COURSE

MEAN OBSTACLE SPACING 14 FT

PLATE 1



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

PATHS OF XM410E1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 16 FT

PLATE 2

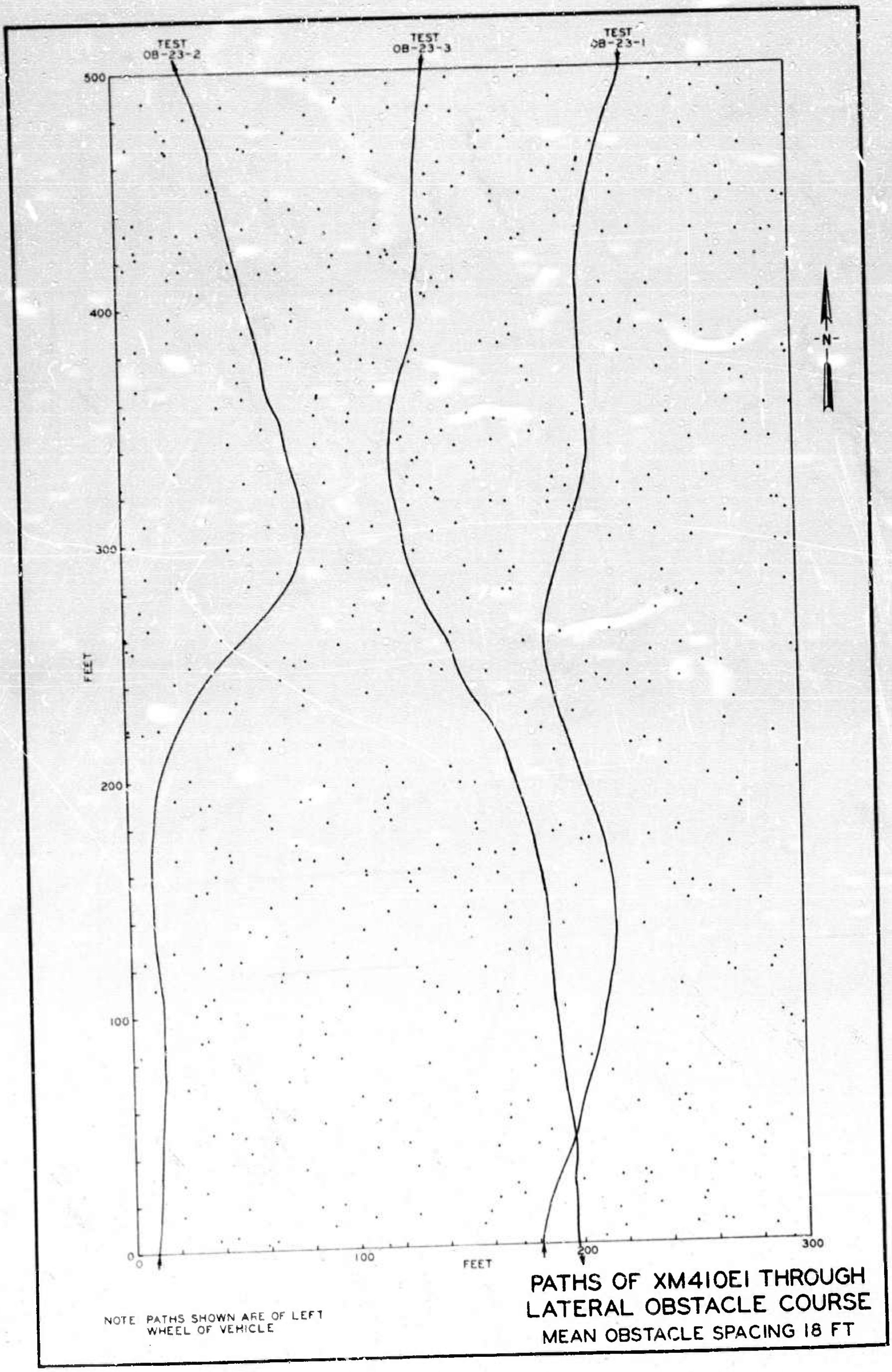
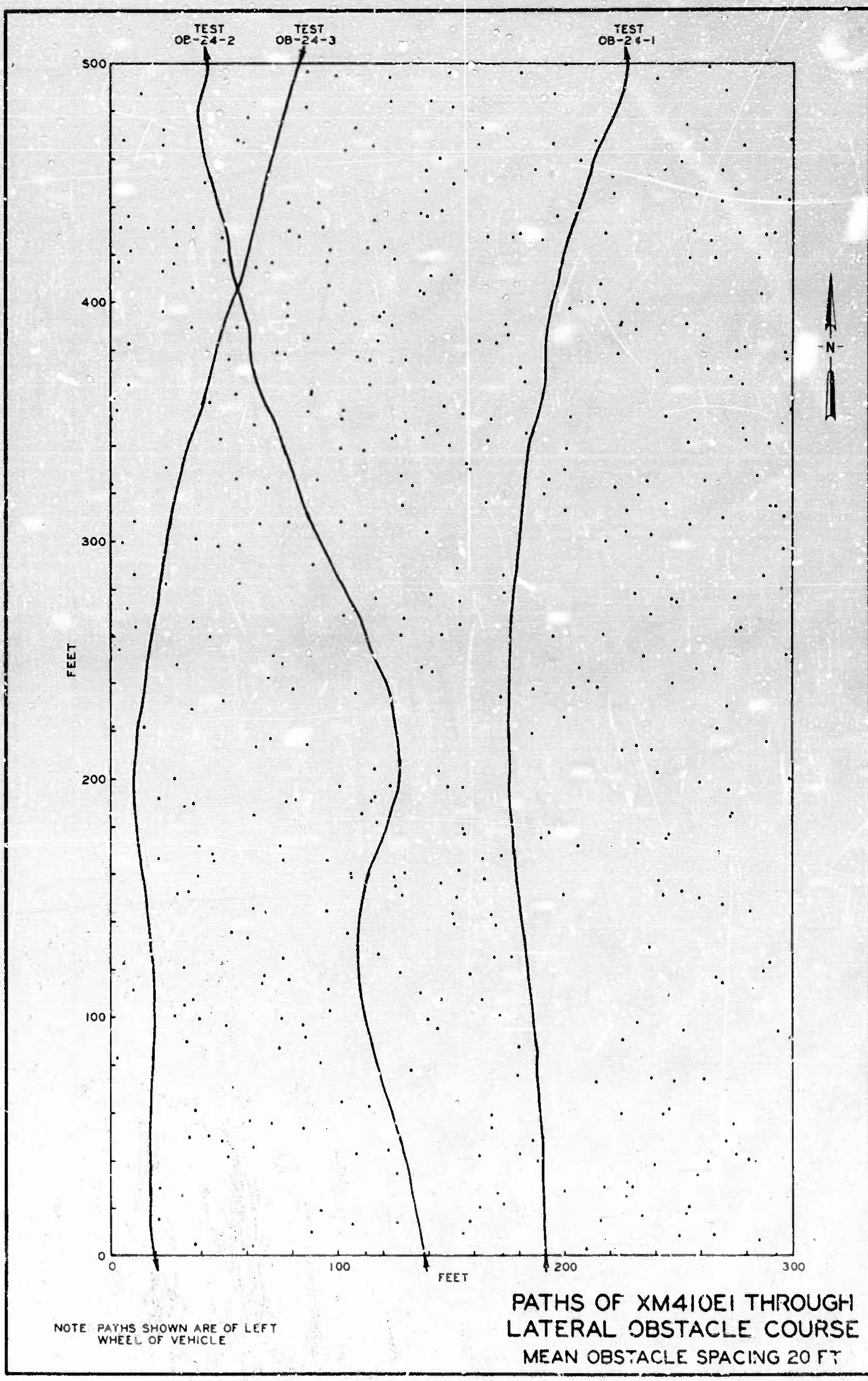
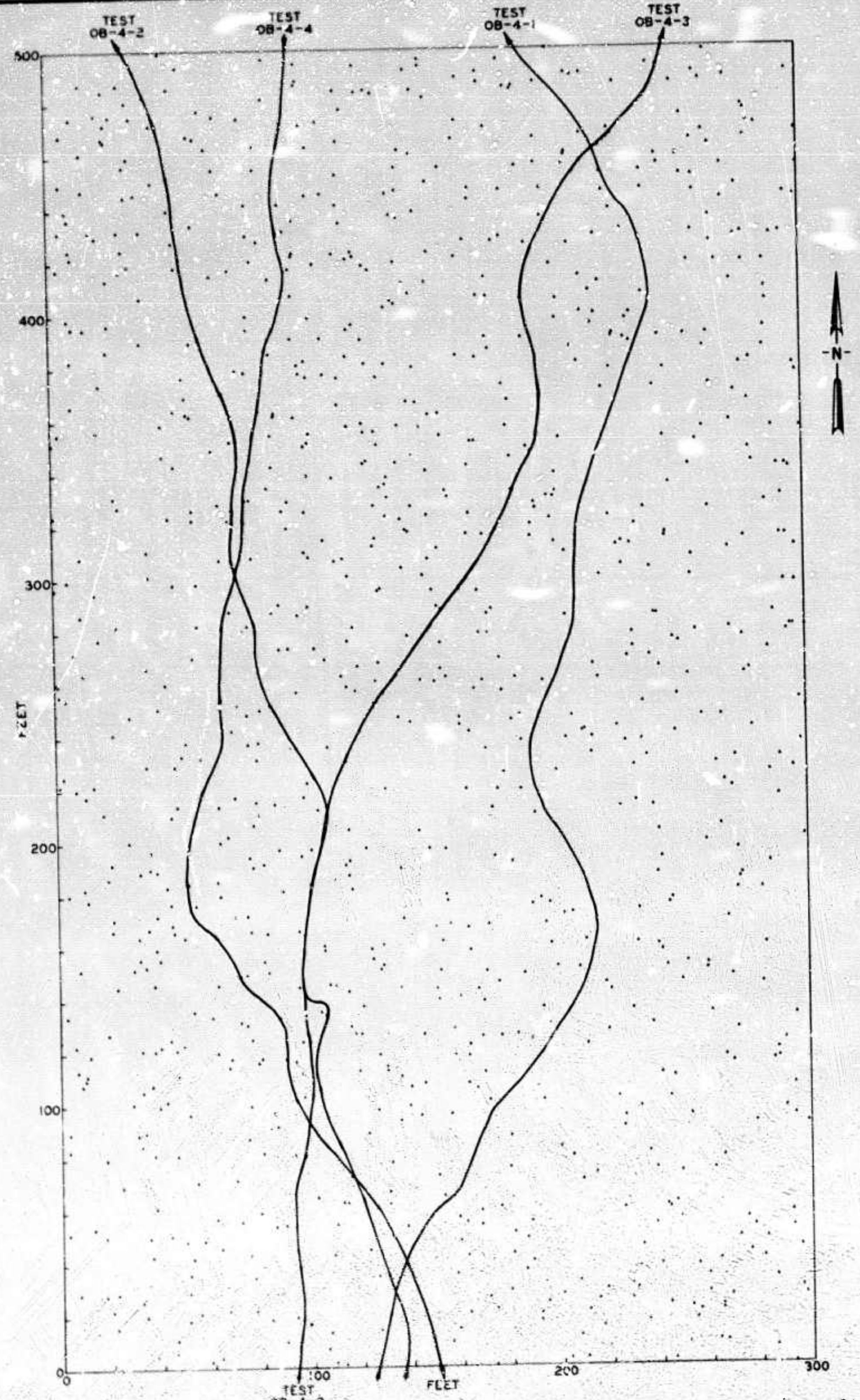

TEST
OB-23-2
TEST
OB-23-3
TEST
OB-23-1
500
400
300
200
100
0
FEET
0
100
200
300
FEET
N
NOTE PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE
PATHS OF XM410E1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 18 FT

PLATE 3



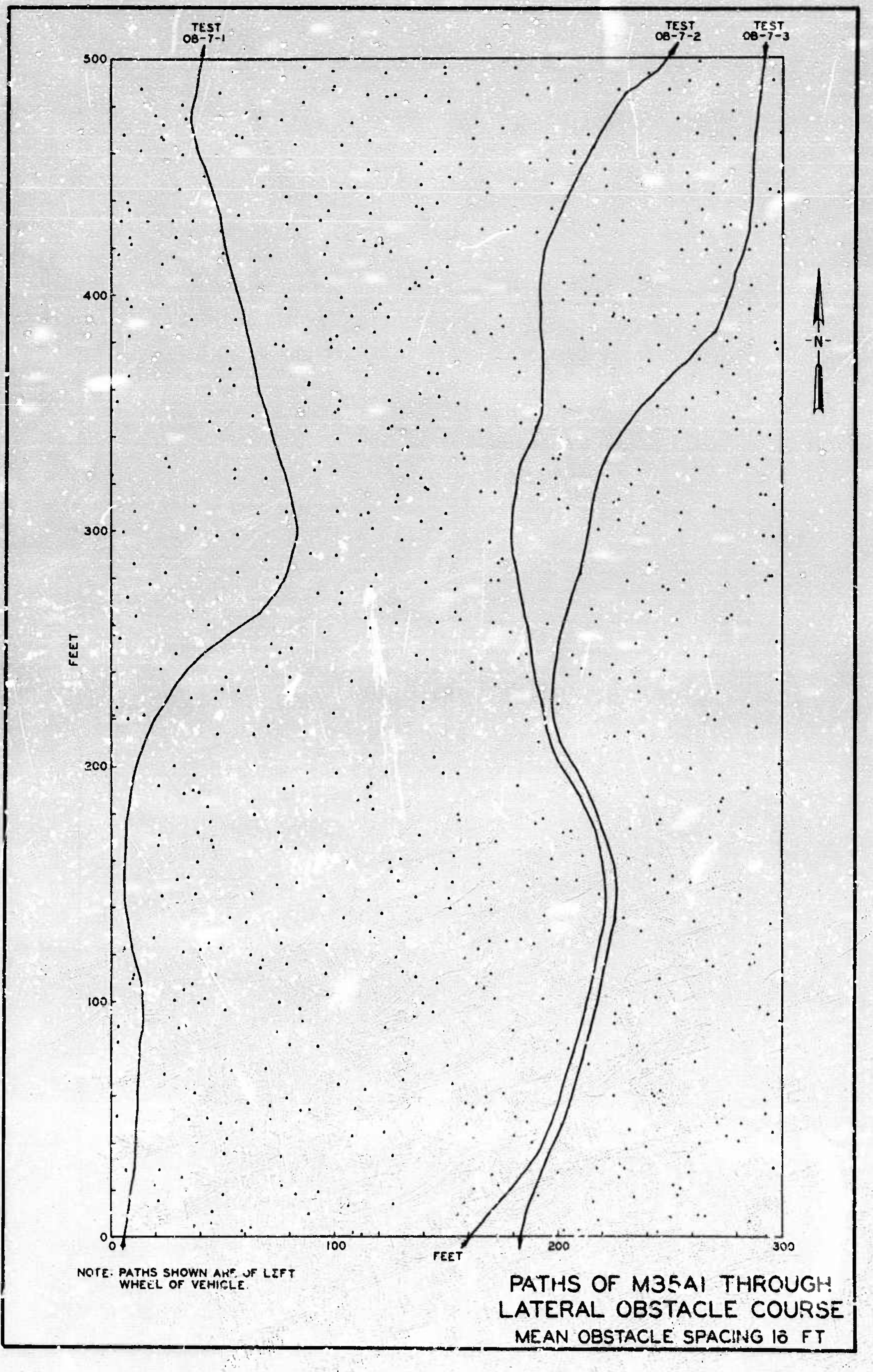
PATHS OF XM410E1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 20 FT



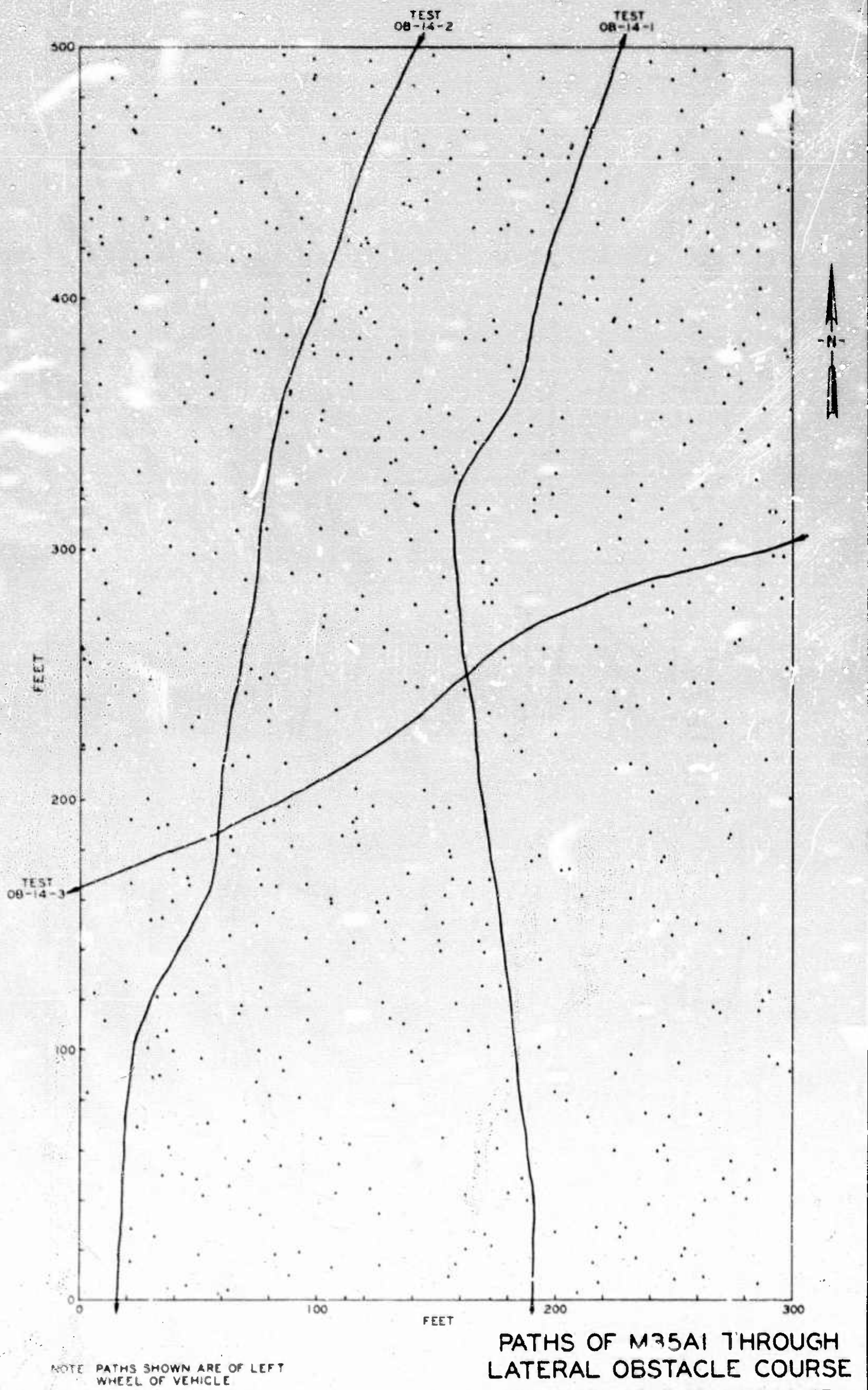
NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

PATHS OF M35A1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 14 FT

PLATE 5

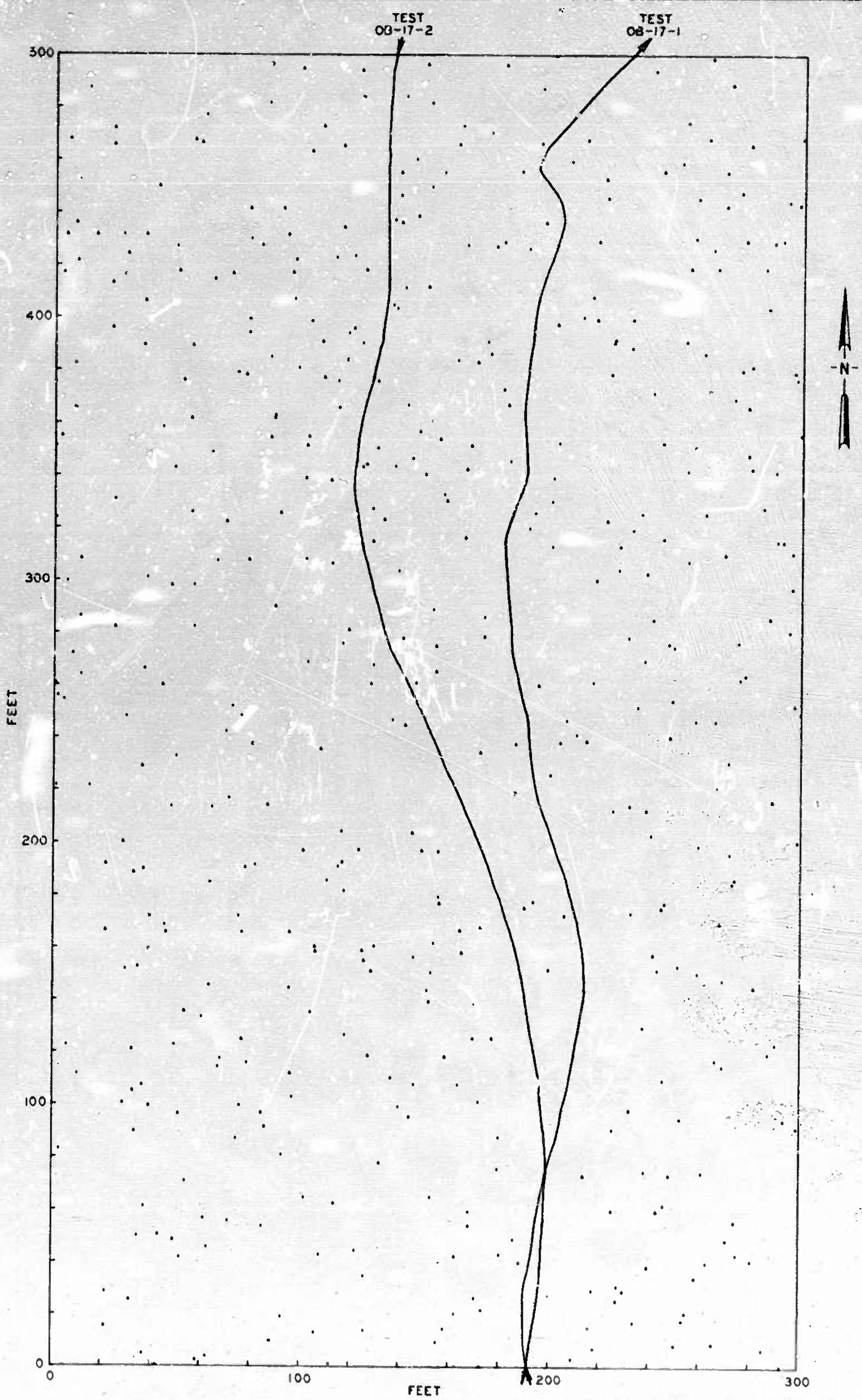


PATHS OF M35A1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 16 FT



PATHS OF M35A1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 18 FT

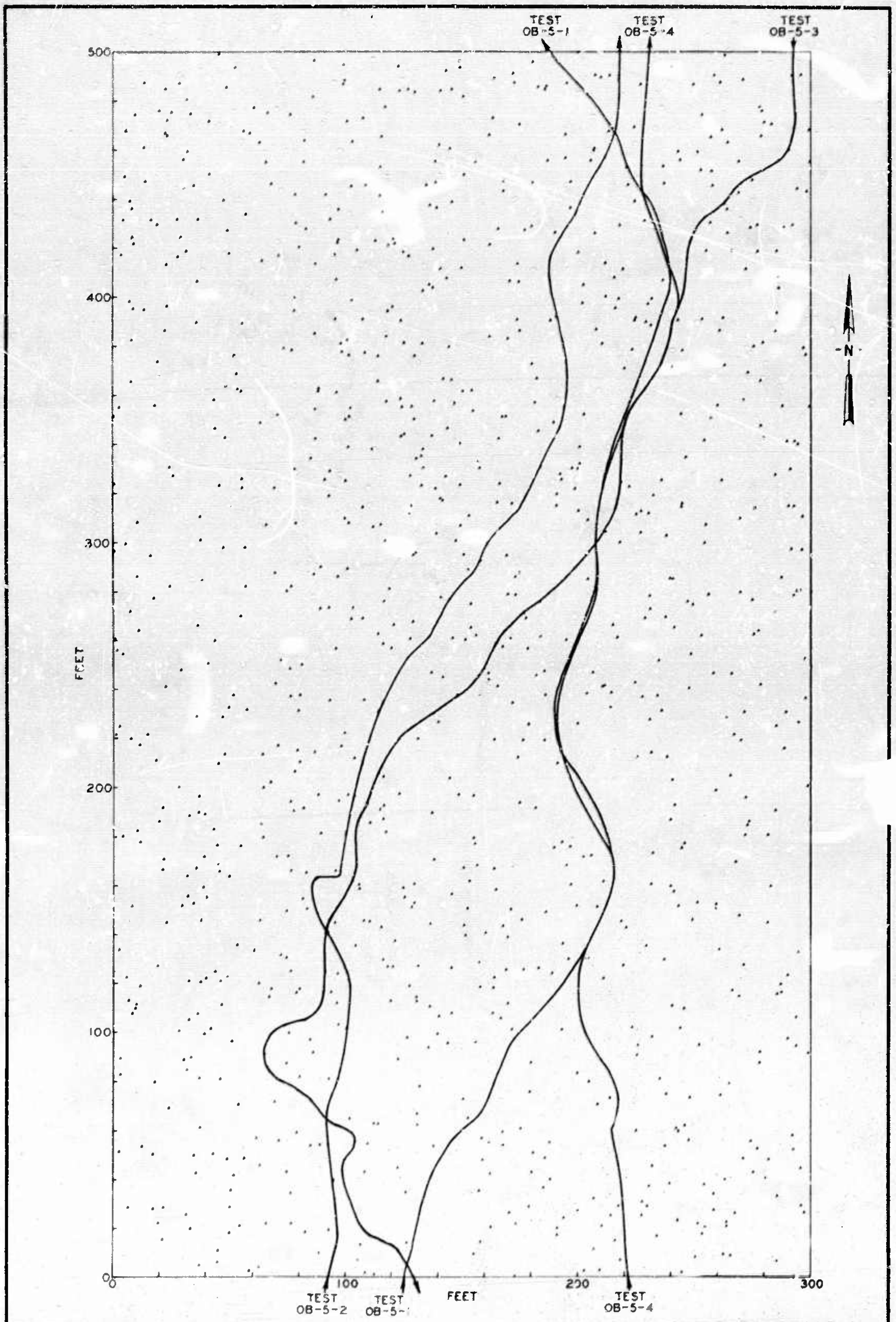
PLATE 7



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

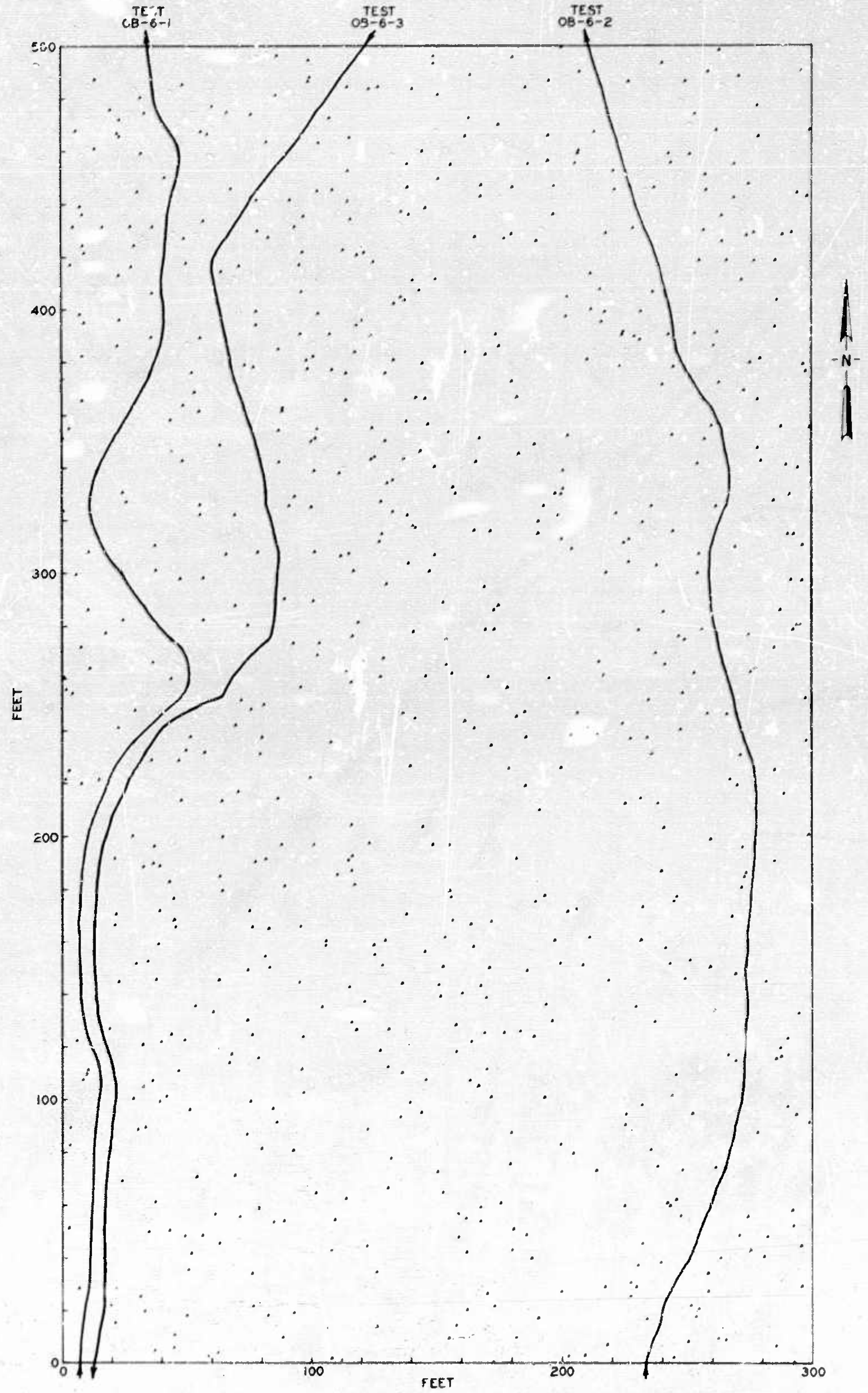
PATHS OF M35A1 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 20 FT

PLATE 8



PATHS OF M113 THROUGH
LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 14 FT

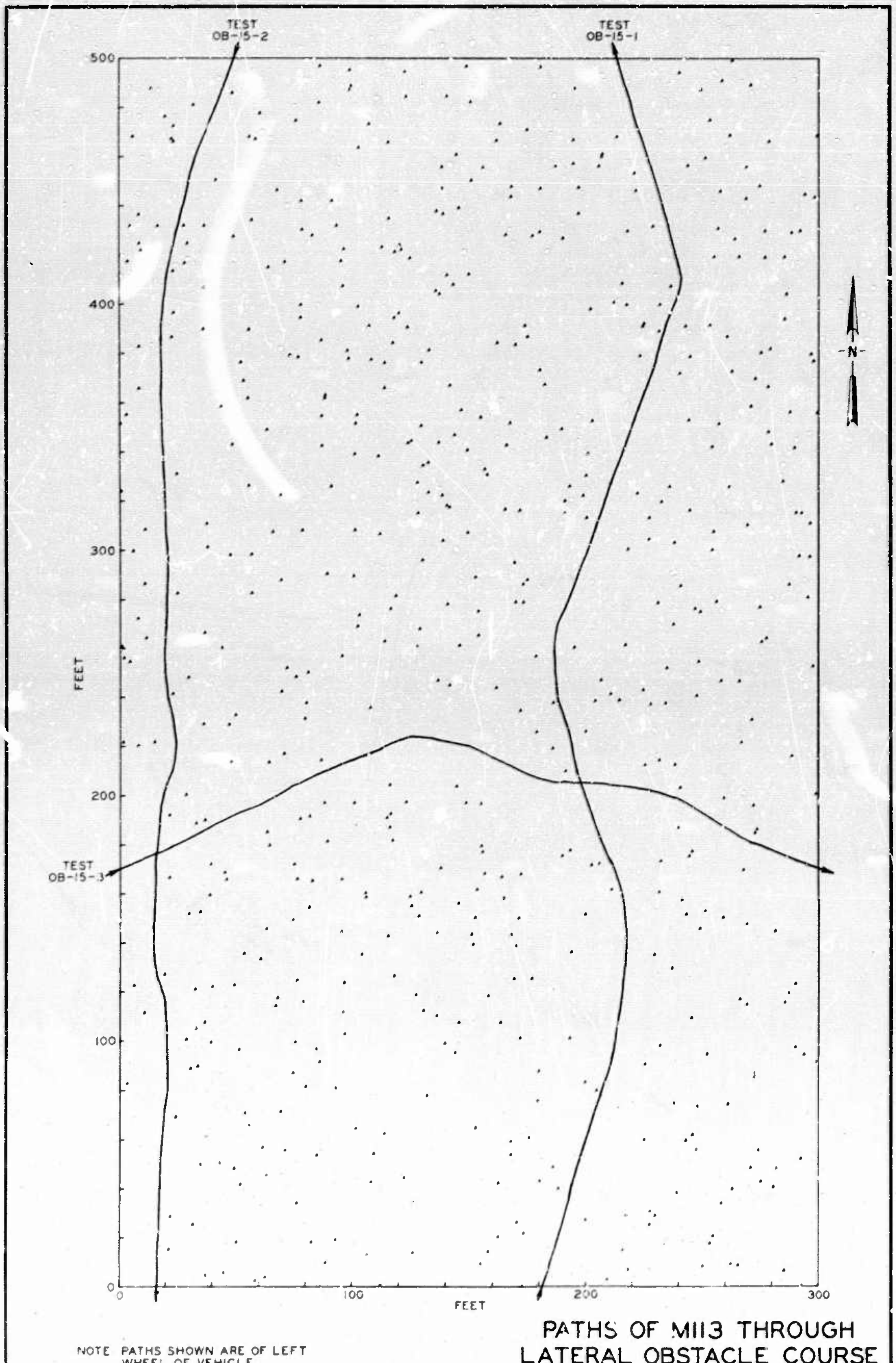
PLATE 9



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

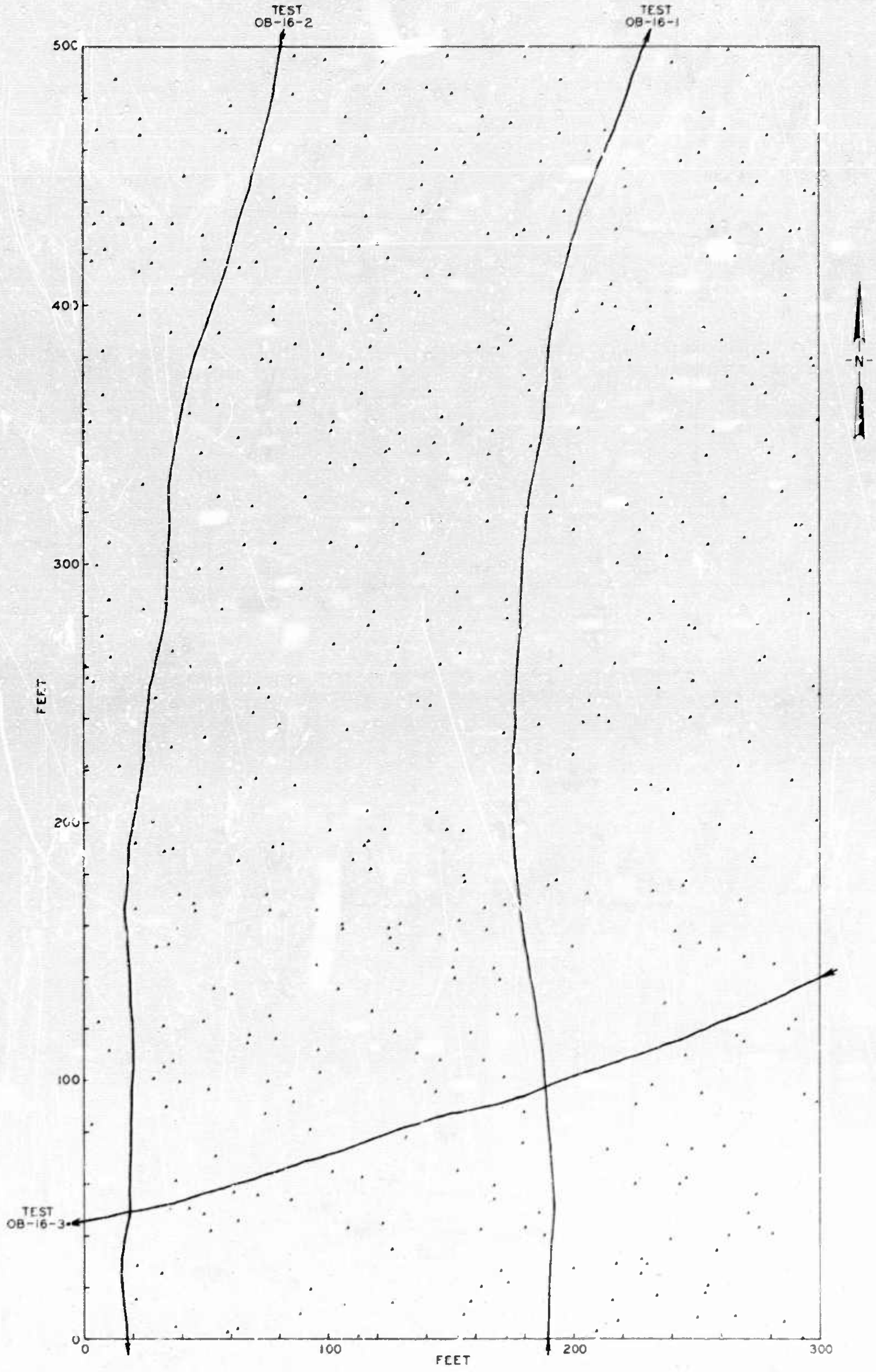
PATHS OF M113 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 16 FT

PLATE 10



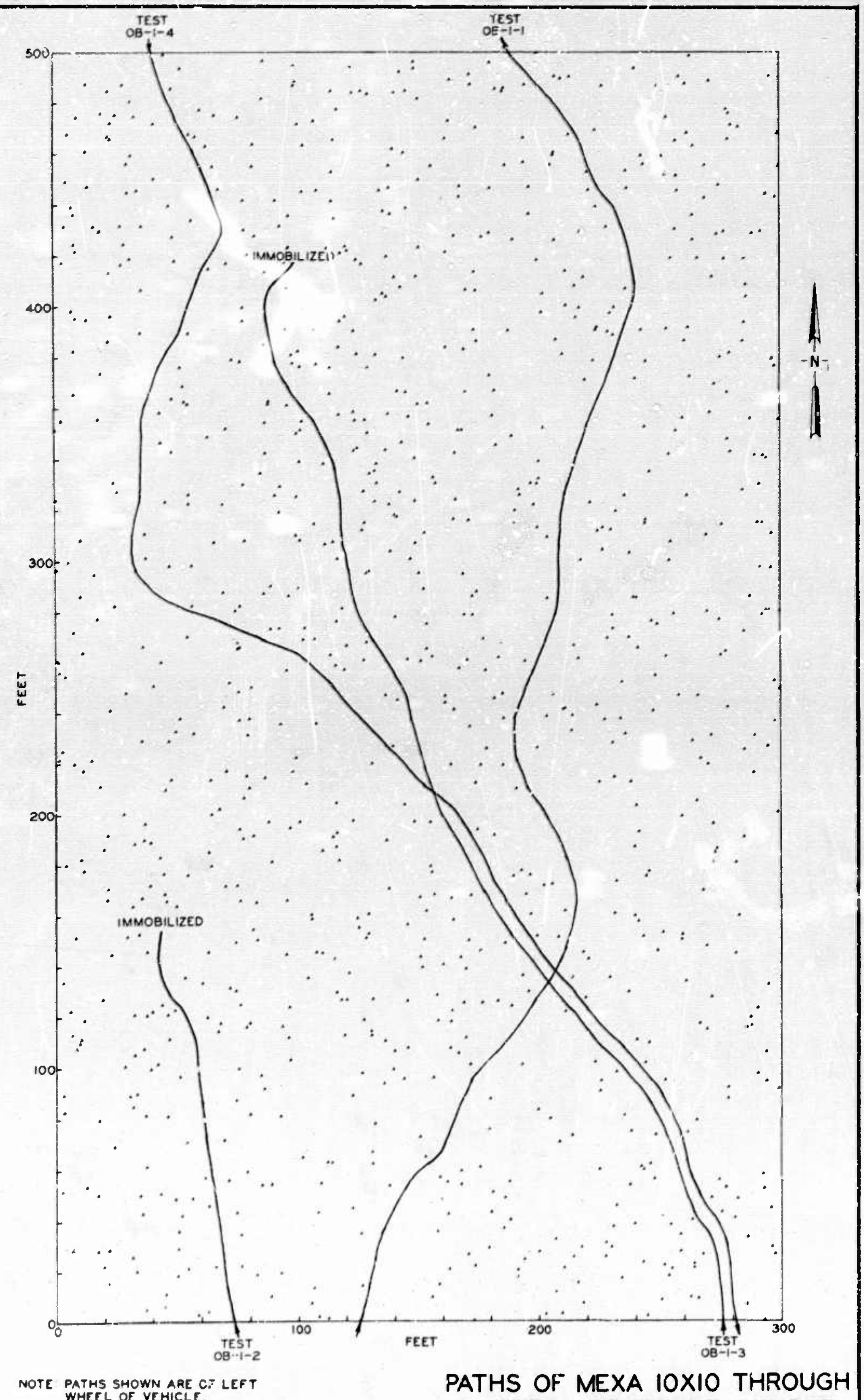
PATHS OF M113 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 18 FT

PLATE 11



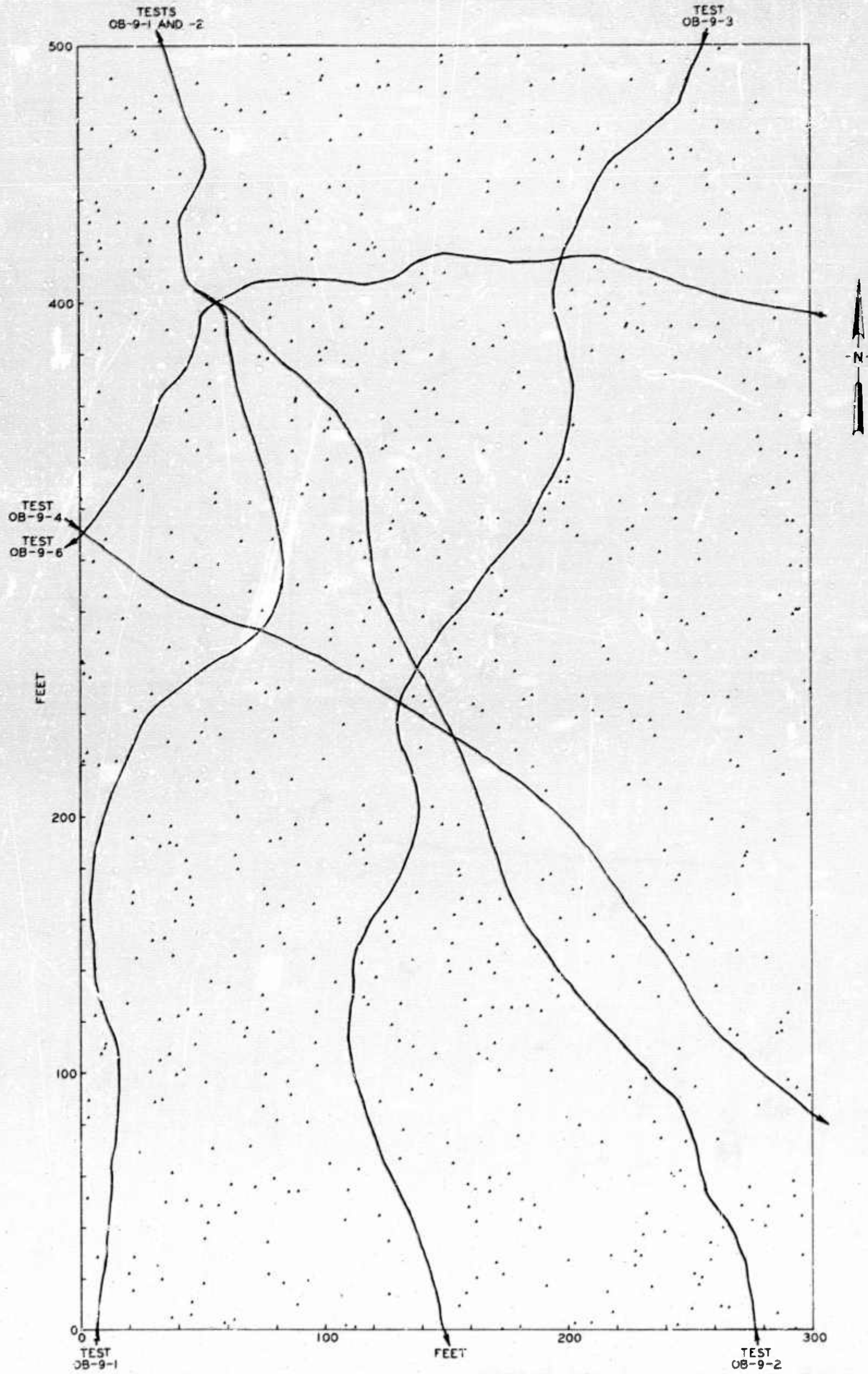
NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

PATHS OF M113 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 20 FT



PATHS OF MEXA 10X10 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 14 FT

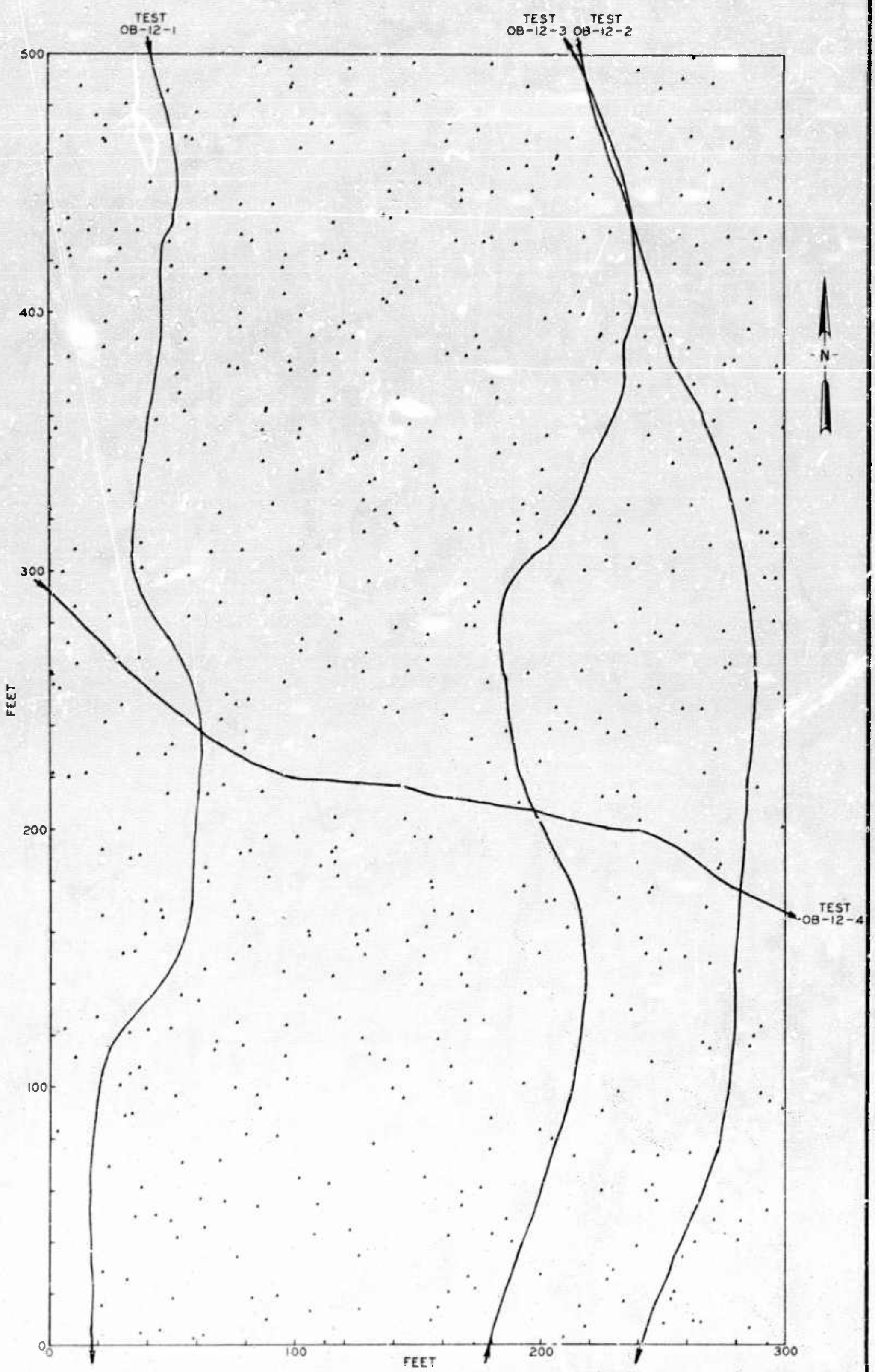
PLATE 13



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

PATHS OF MEXA 10X10 THROUGH LATERAL OBSTACLE COURSE

MEAN OBSTACLE SPACING 16 FT

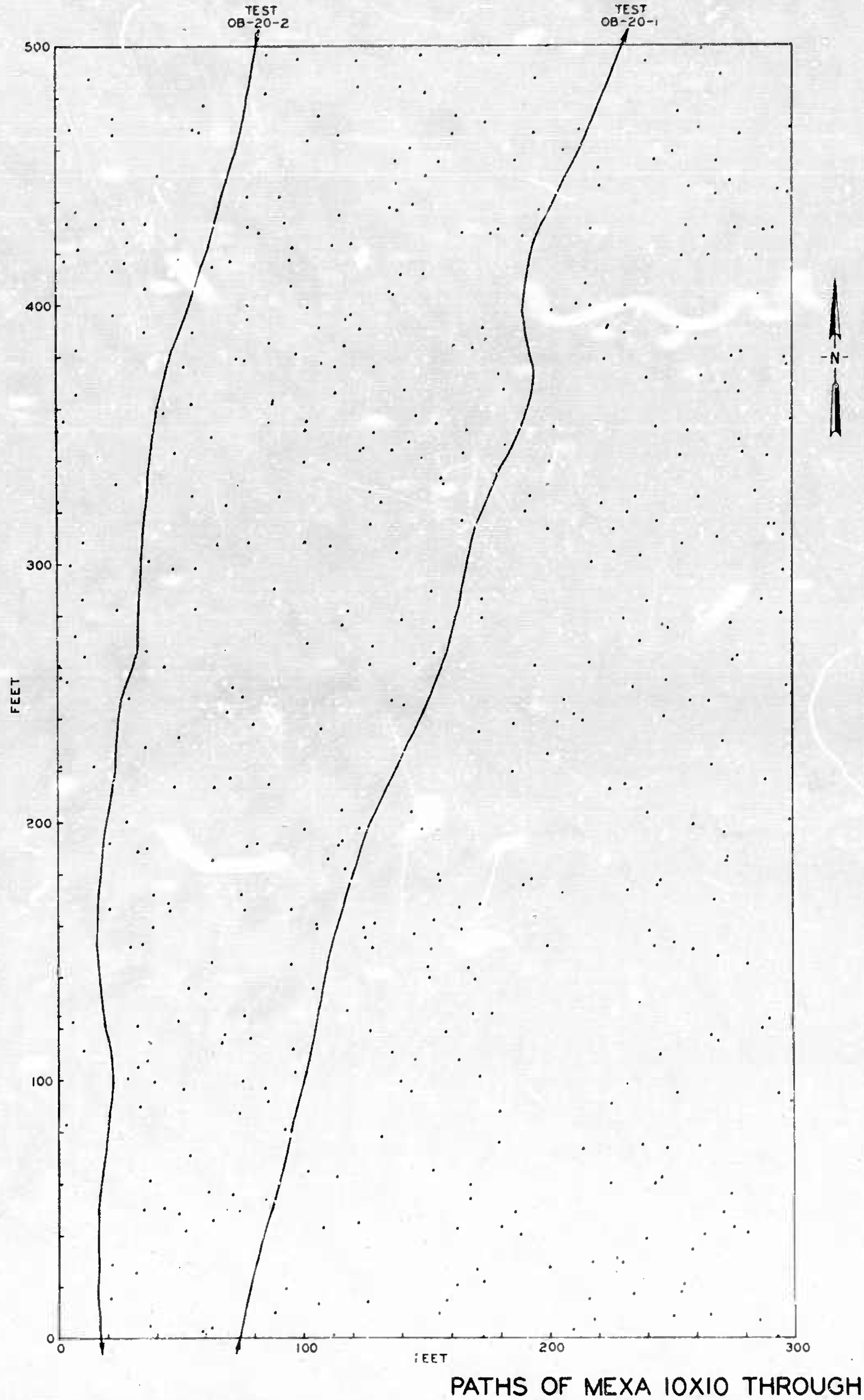


PATHS OF MEXA 10X10 THROUGH LATERAL OBSTACLE COURSE

MEAN OBSTACLE SPACING 18 FT

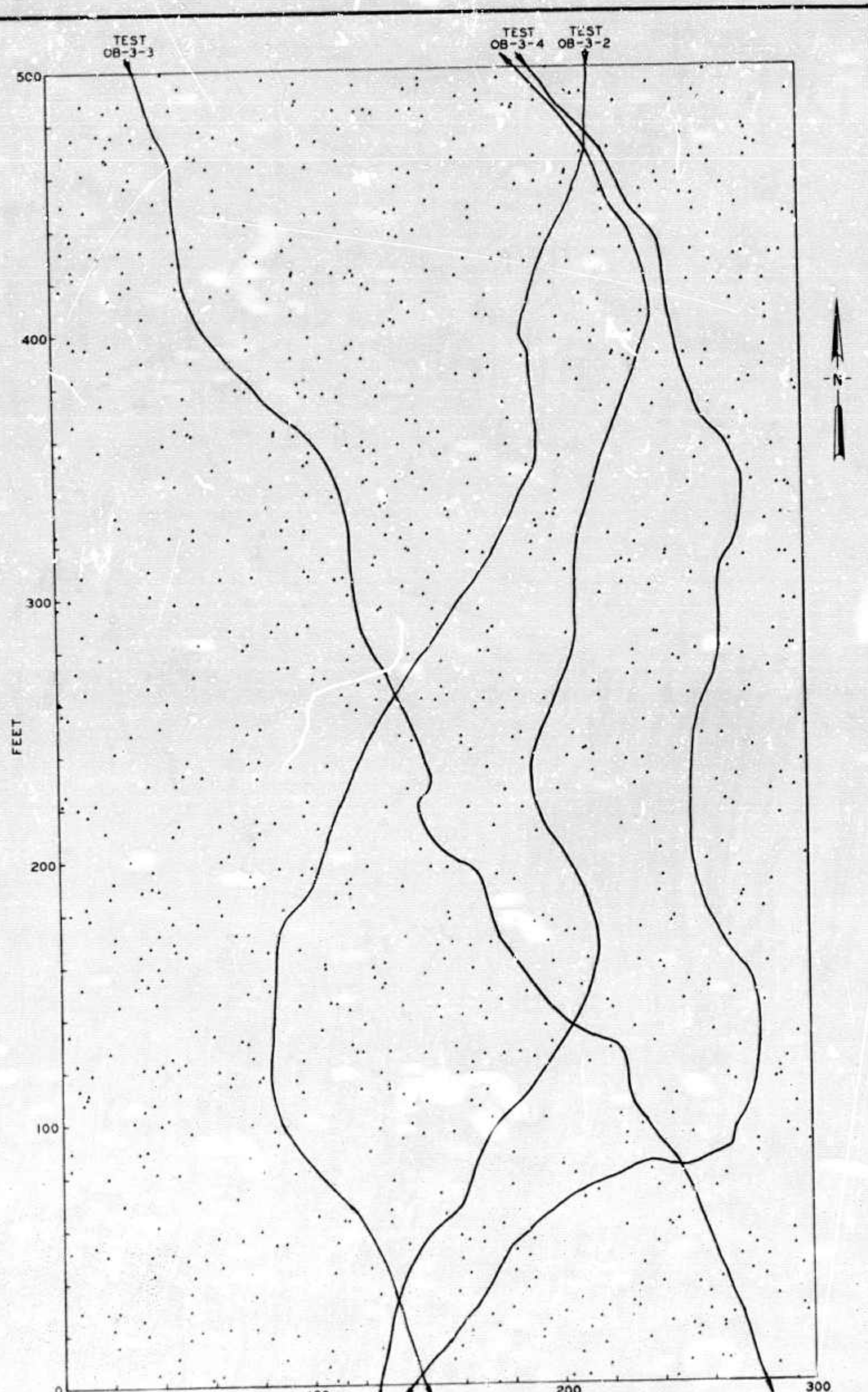
NOTE PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

PLATE 15



NOTE PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

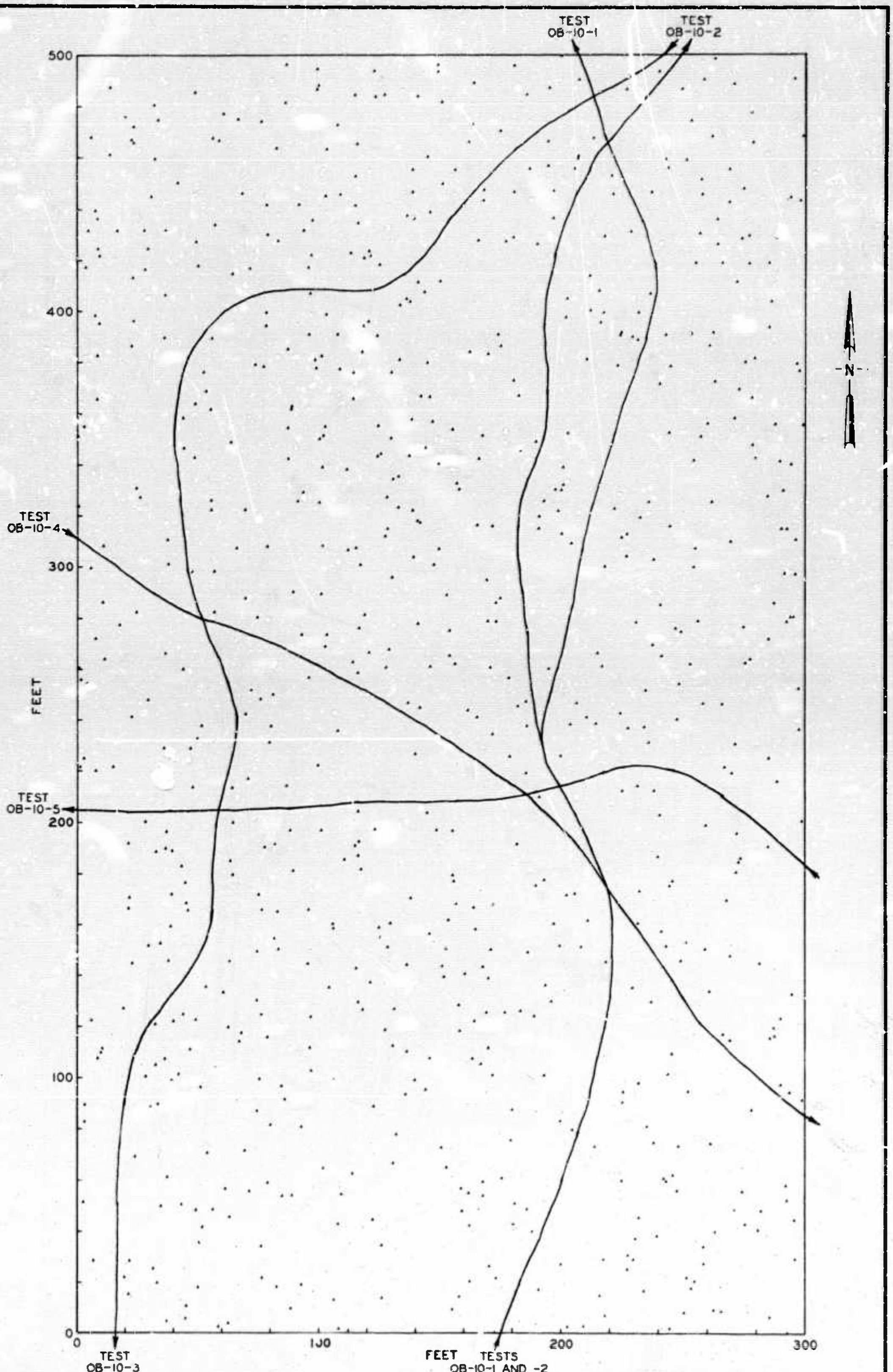
PATHS OF MEXA 10X10 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 20 FT



NOTE PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

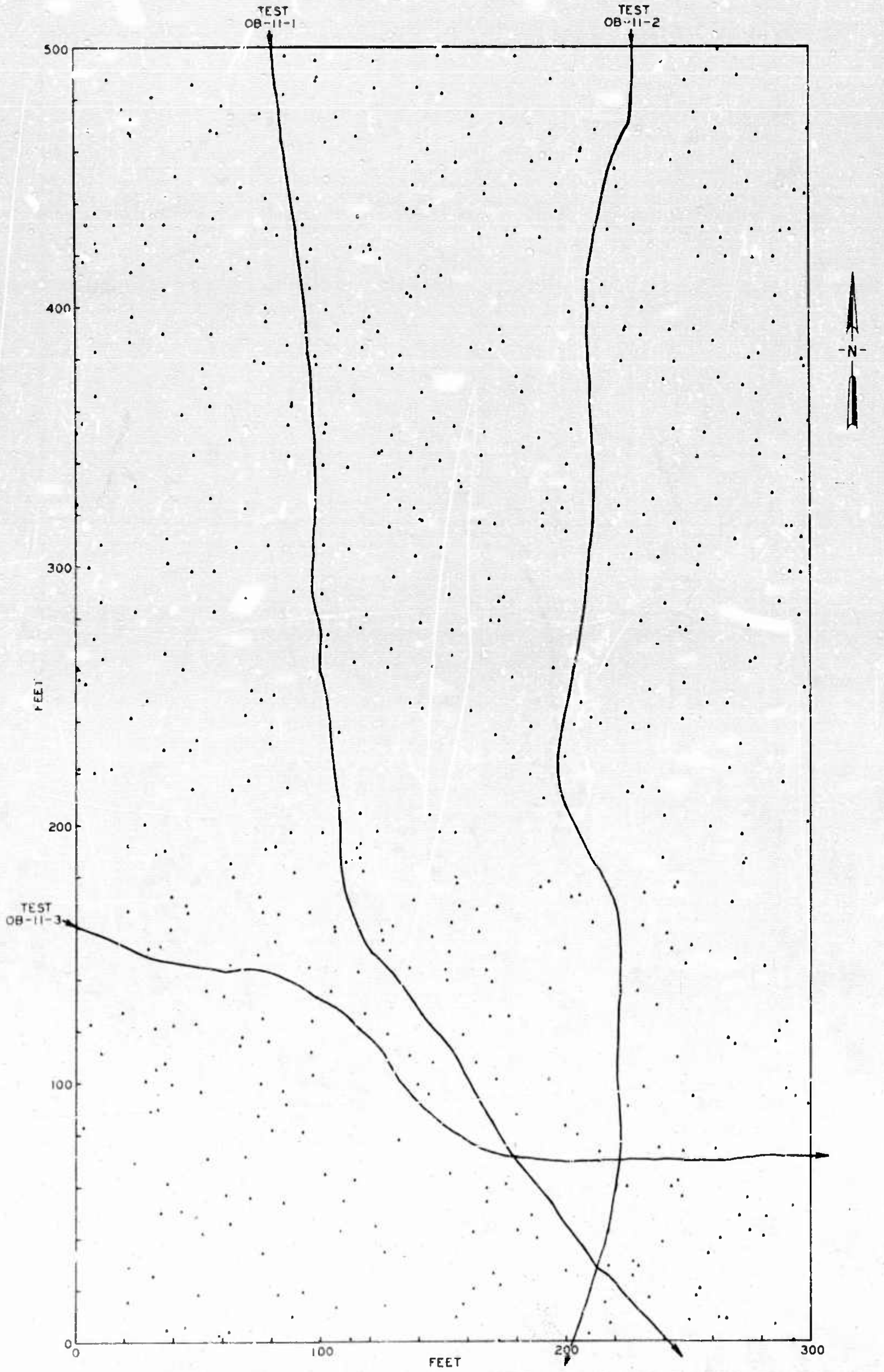
PATHS OF MEXA 8X8 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 14 FT

PLATE 17



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

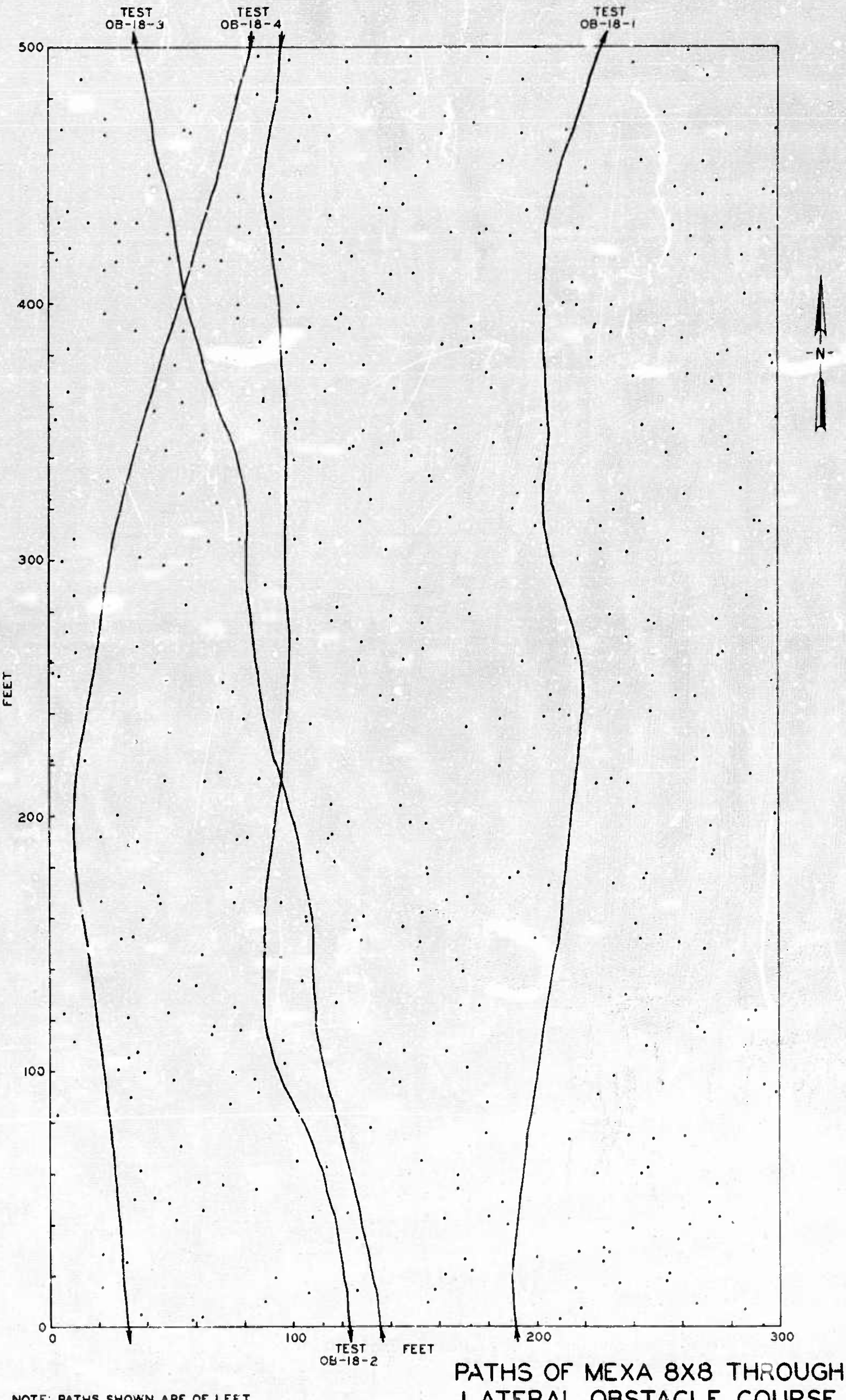
PATHS OF MEXA 8X8 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 16 FT



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

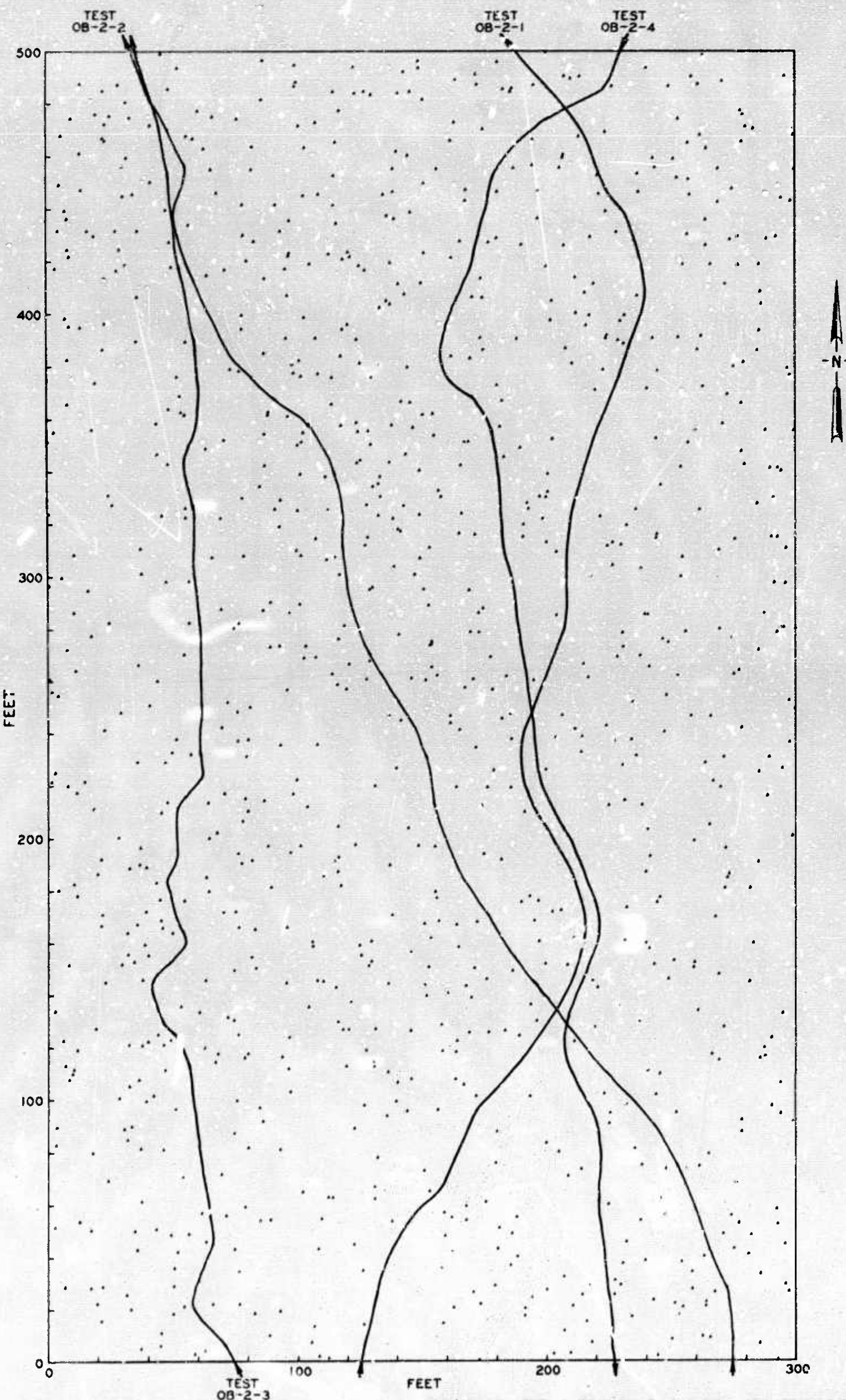
PATHS OF MEXA 8X8 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 18 FT

PLATE 19



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

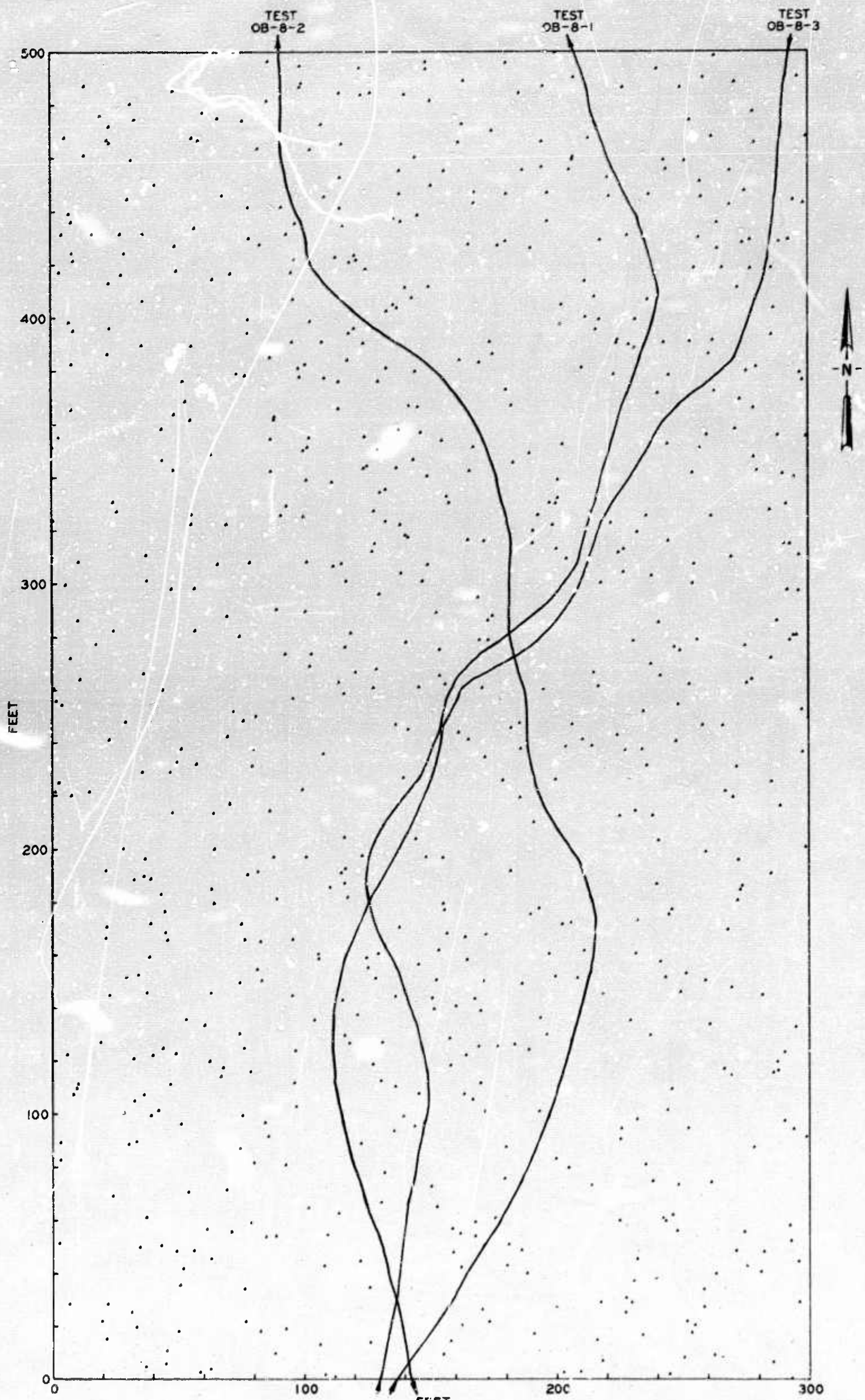
PATHS OF MEXA 8X8 THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 20 FT



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

PATHS OF MEXA TRACK THROUGH LATERAL OBSTACLE COURSE
MEAN OBSTACLE SPACING 14 FT

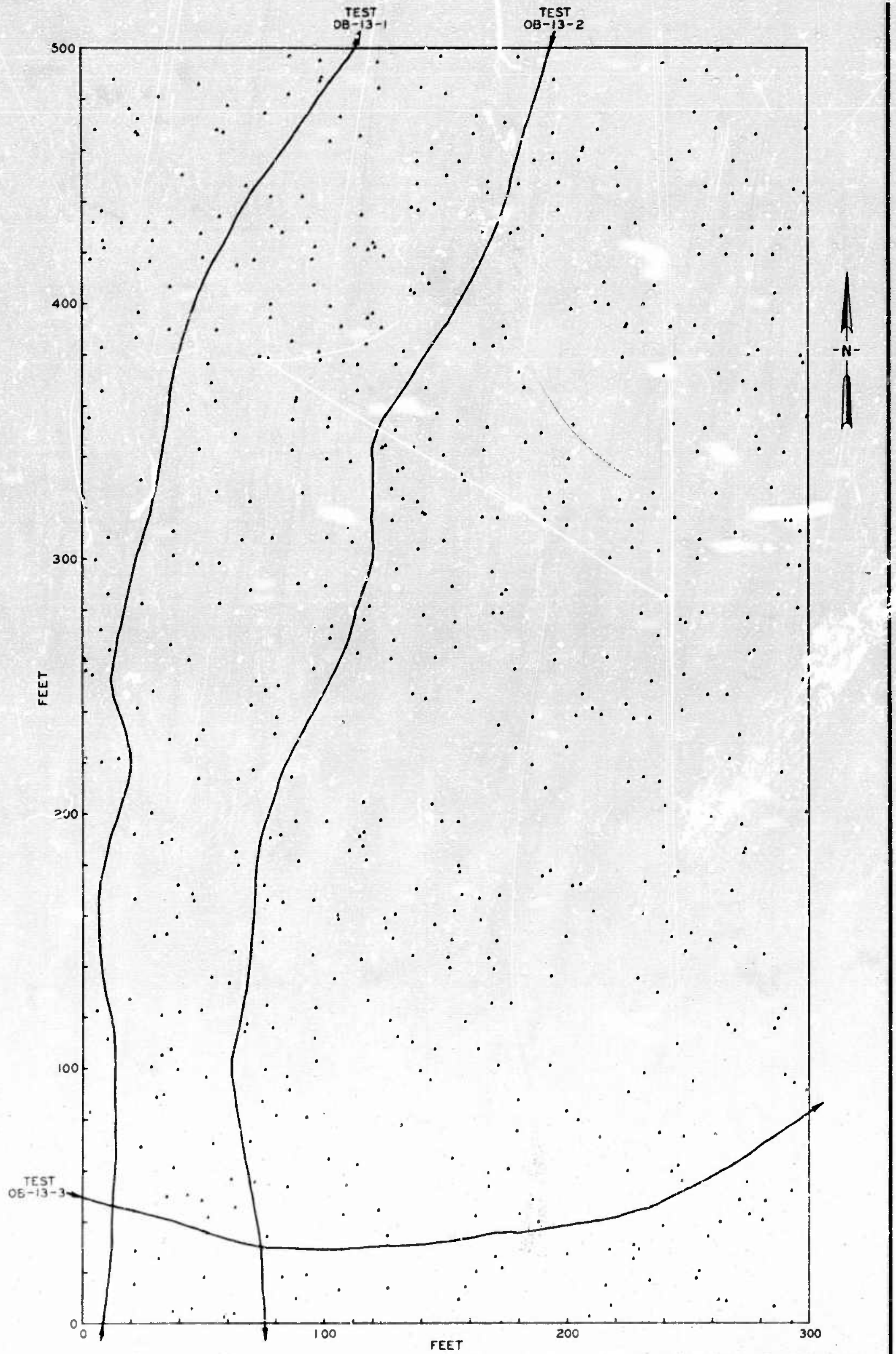
PLATE 21



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

PATHS OF MEXA TRACK THROUGH LATERAL OBSTACLE COURSE

MEAN OBSTACLE SPACING 16 FT

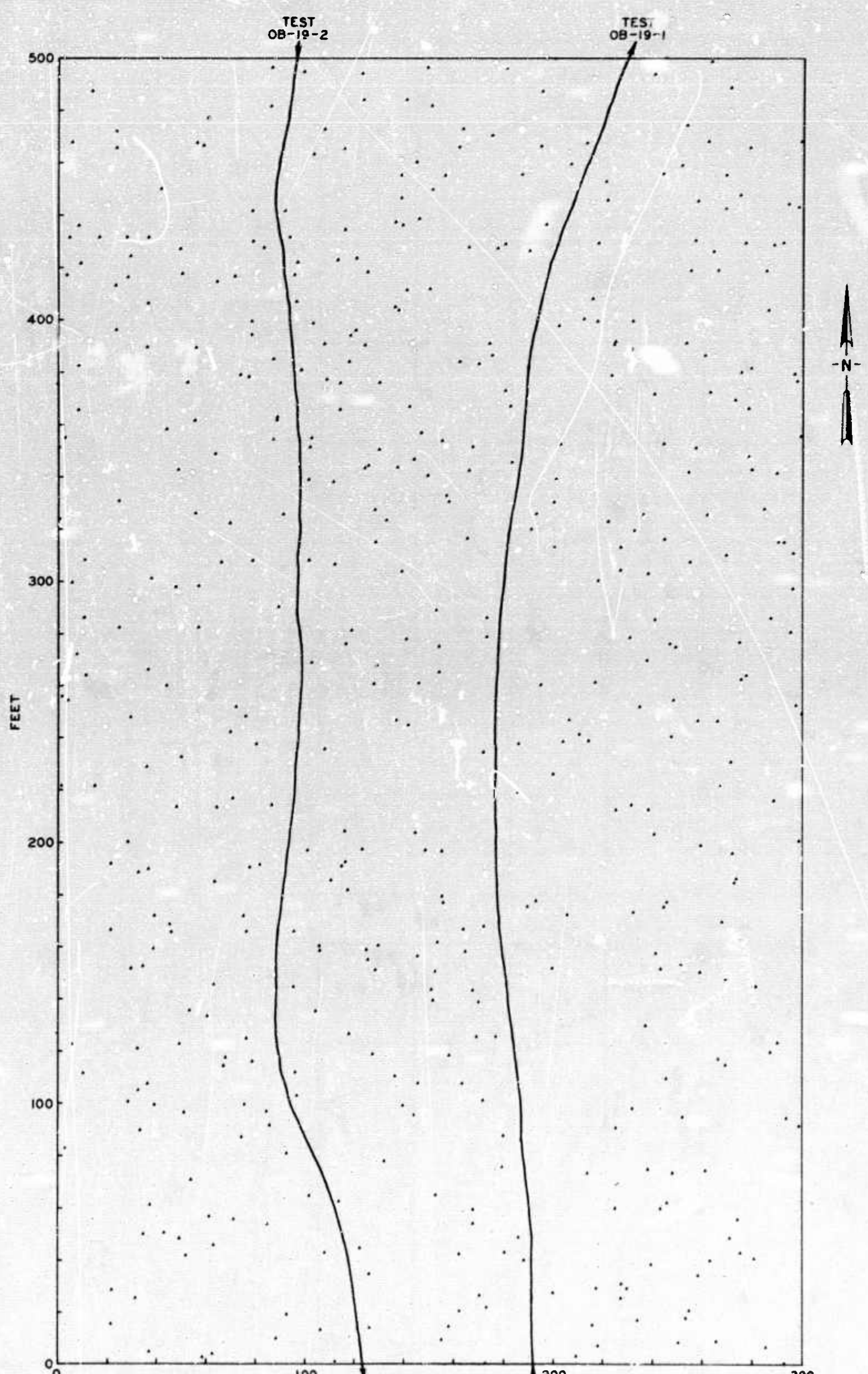


PATHS OF MEXA TRACK THROUGH LATERAL OBSTACLE COURSE

MEAN OBSTACLE SPACING 18 FT

NOTE PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE

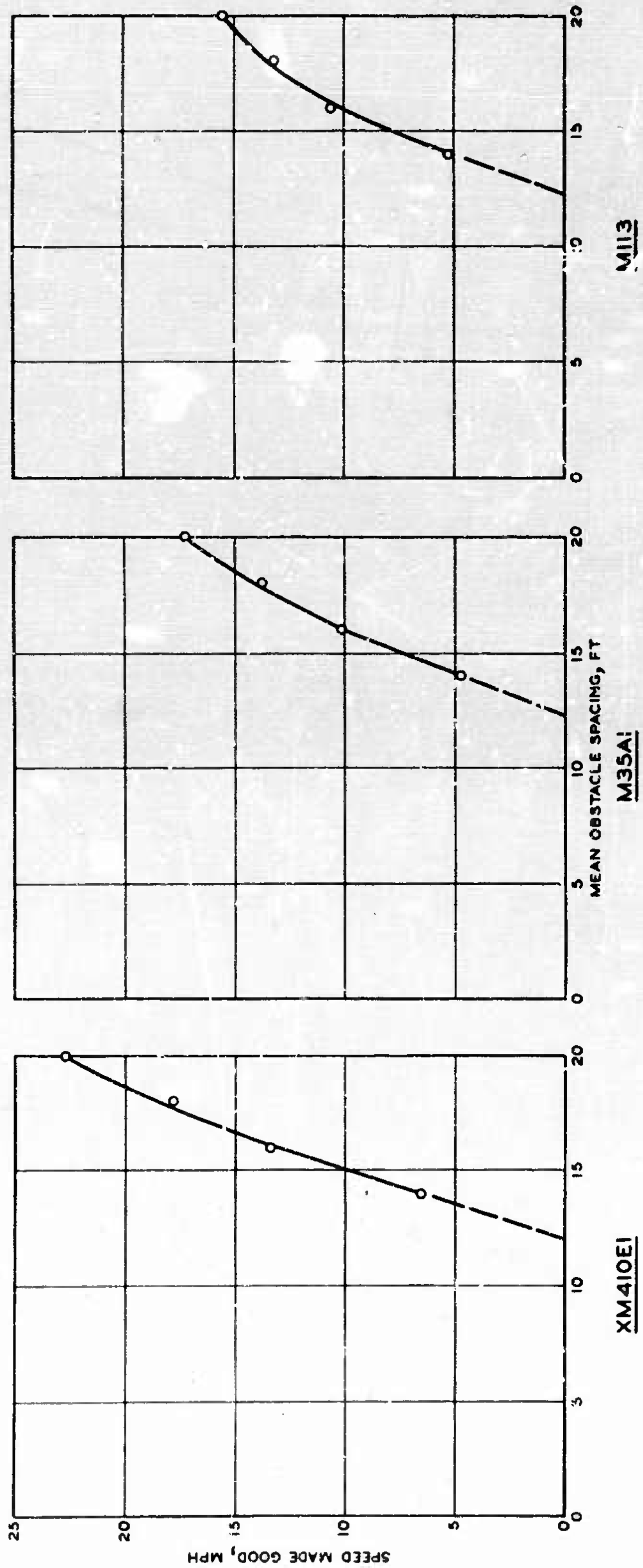
PLATE 23



NOTE: PATHS SHOWN ARE OF LEFT WHEEL OF VEHICLE.

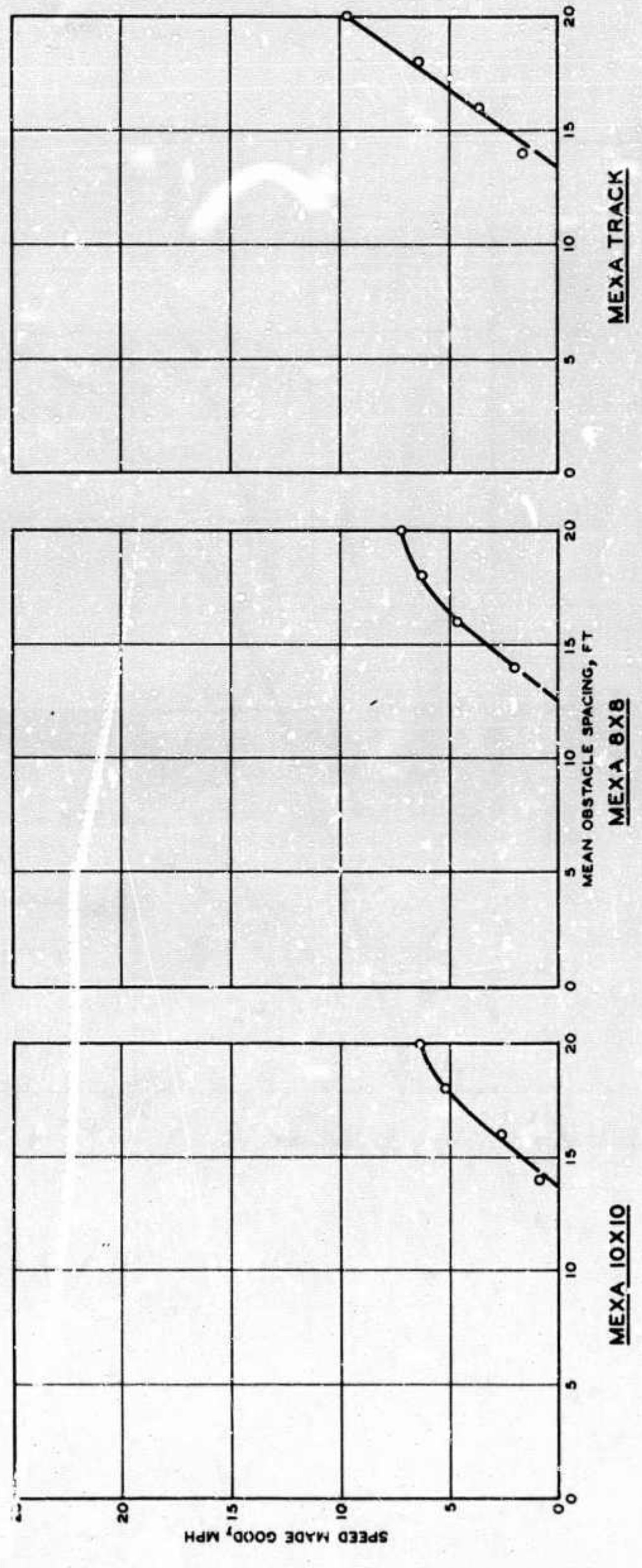
PATHS OF MEXA TRACK THROUGH LATERAL OBSTACLE COURSE

MEAN OBSTACLE SPACING 20 FT



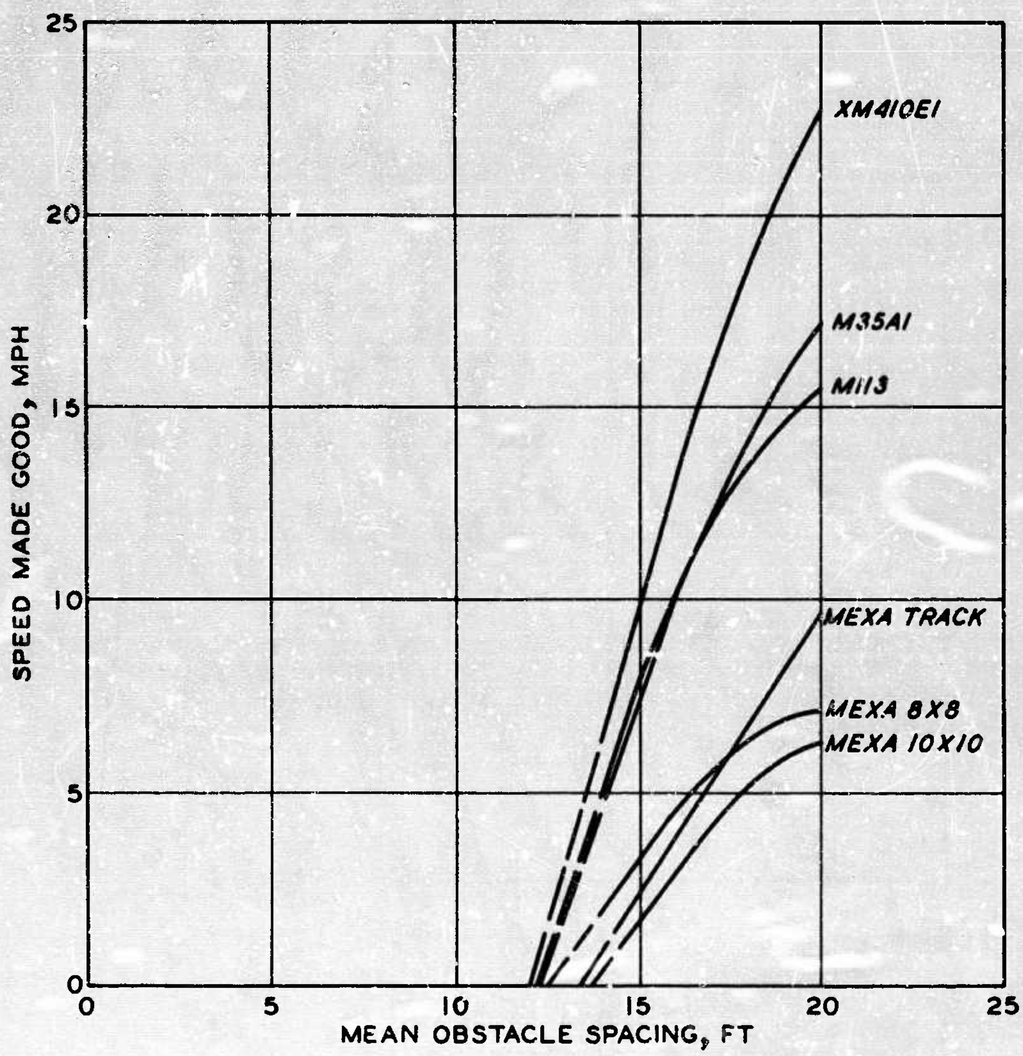
SPEED-MEAN OBSTACLE SPACING RELATIONS
XM410E1, M35A1, AND M113

PLATE 25



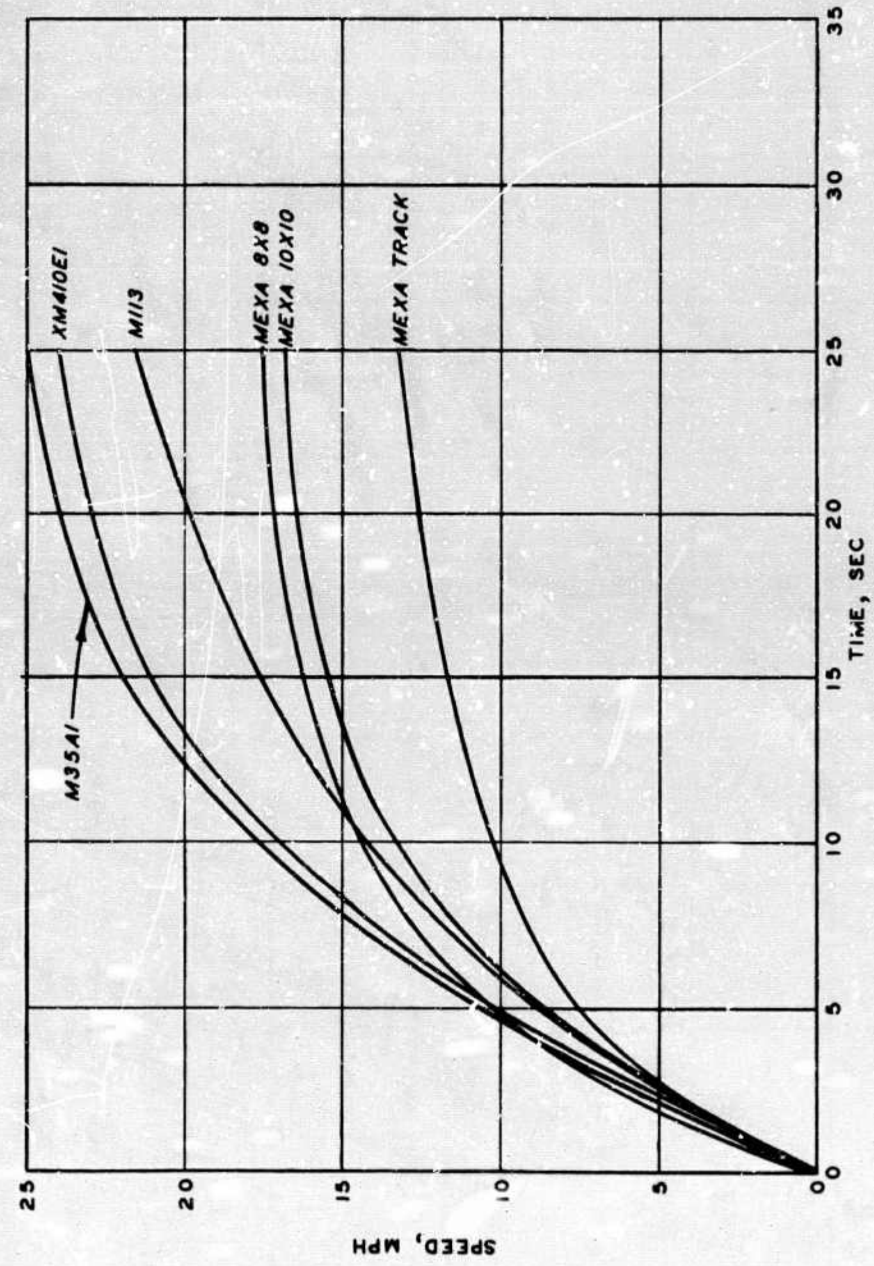
SPEED-MEAN OBSTACLE SPACING RELATIONS

MEXA 10X10, MEXA 8X8, AND MEXA TRACK



SPEED-MEAN OBSTACLE SPACING RELATIONS

MILITARY AND MEXA VEHICLES



HARD-SURFACE
ACCELERATION TESTS

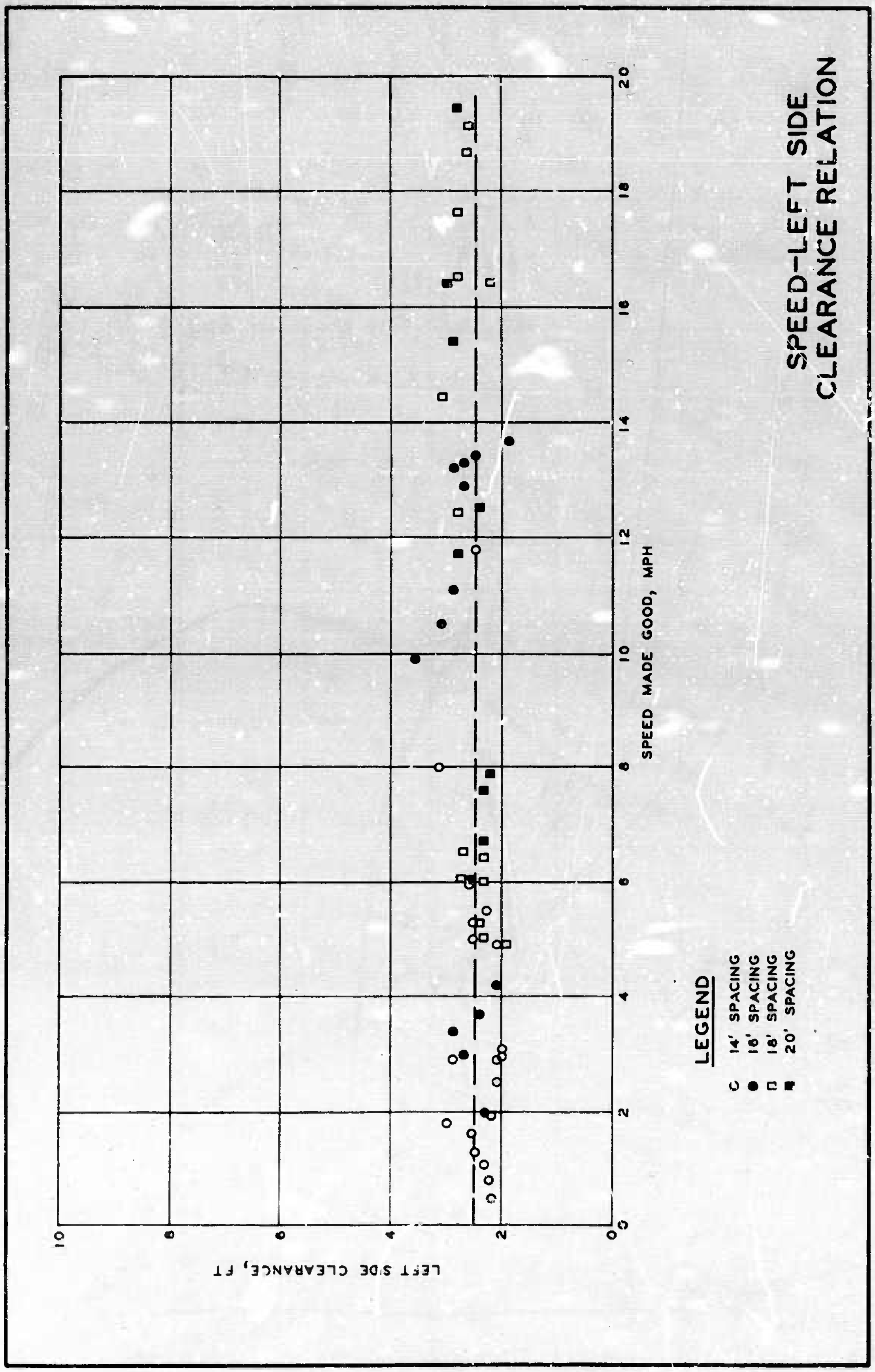
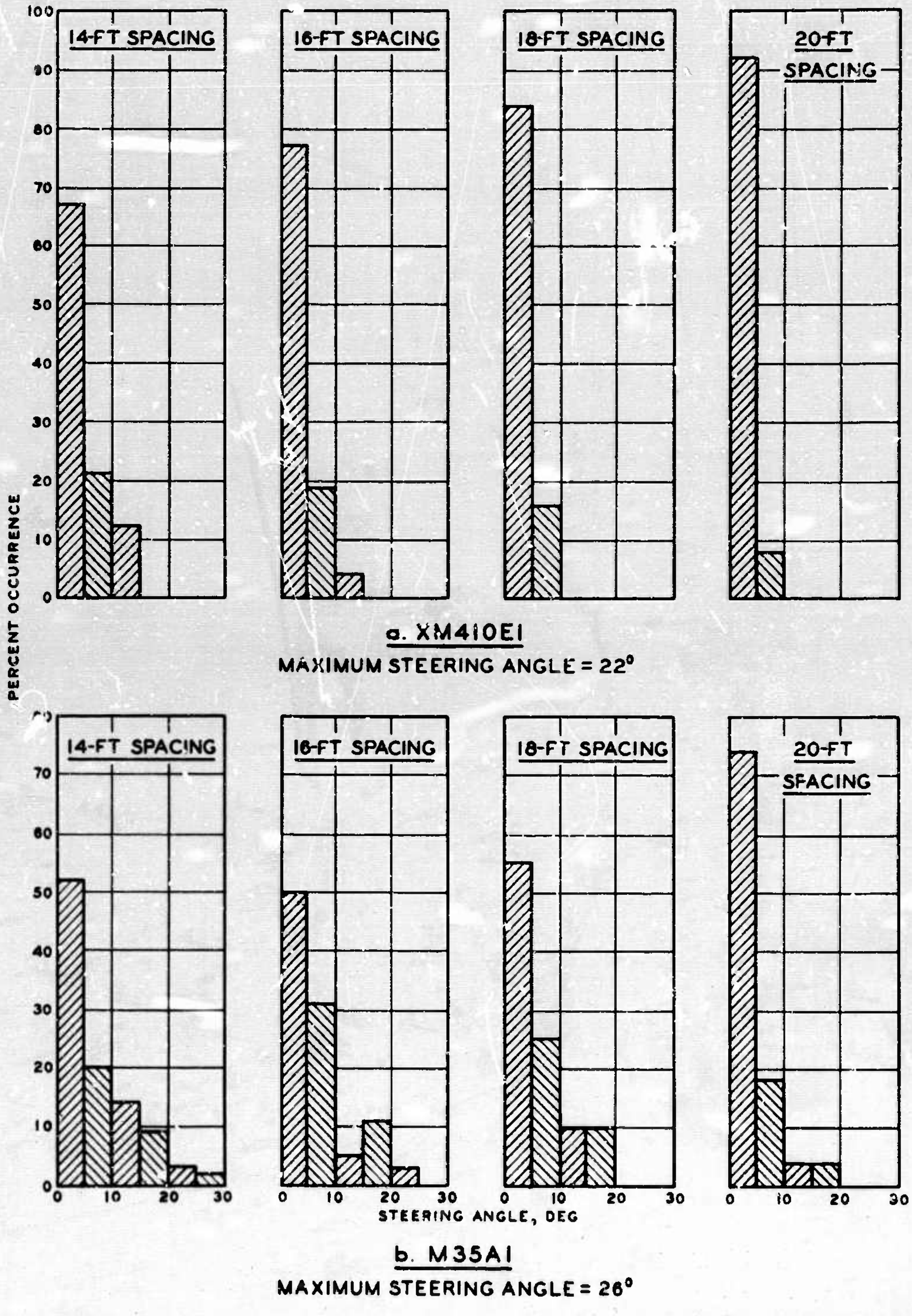
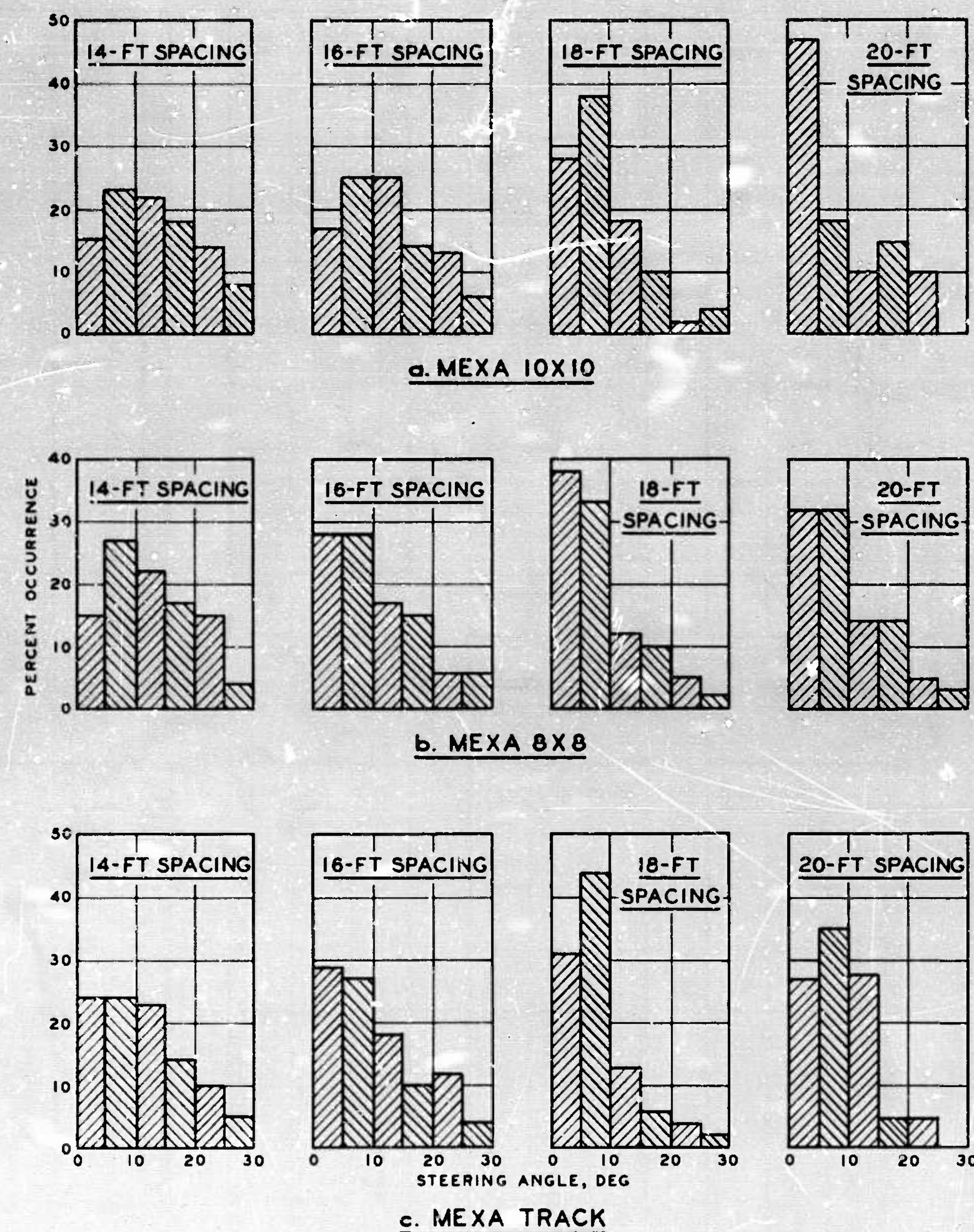

SPEED-LEFT SIDE CLEARANCE RELATION
LEFT SIDE CLEARANCE, FT
SPEED MADE GOOD, MPH
0
2
4
6
8
10
12
14
16
18
20
LEGEND
14' SPACING
16' SPACING
18' SPACING
20' SPACING

PLATE 29

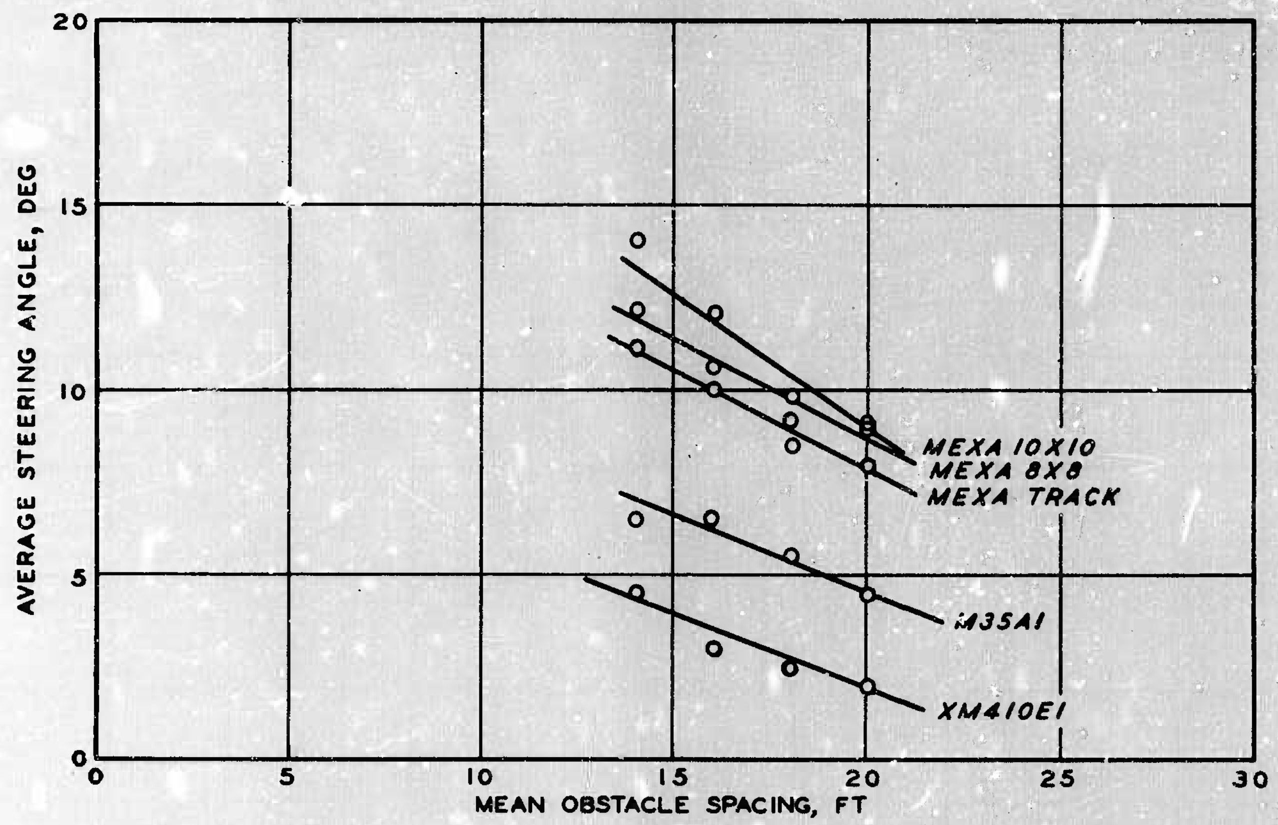


FREQUENCY OF STEERING ANGLE OCCURRENCE
MILITARY VEHICLES
(XM410E1 AND M35A1)

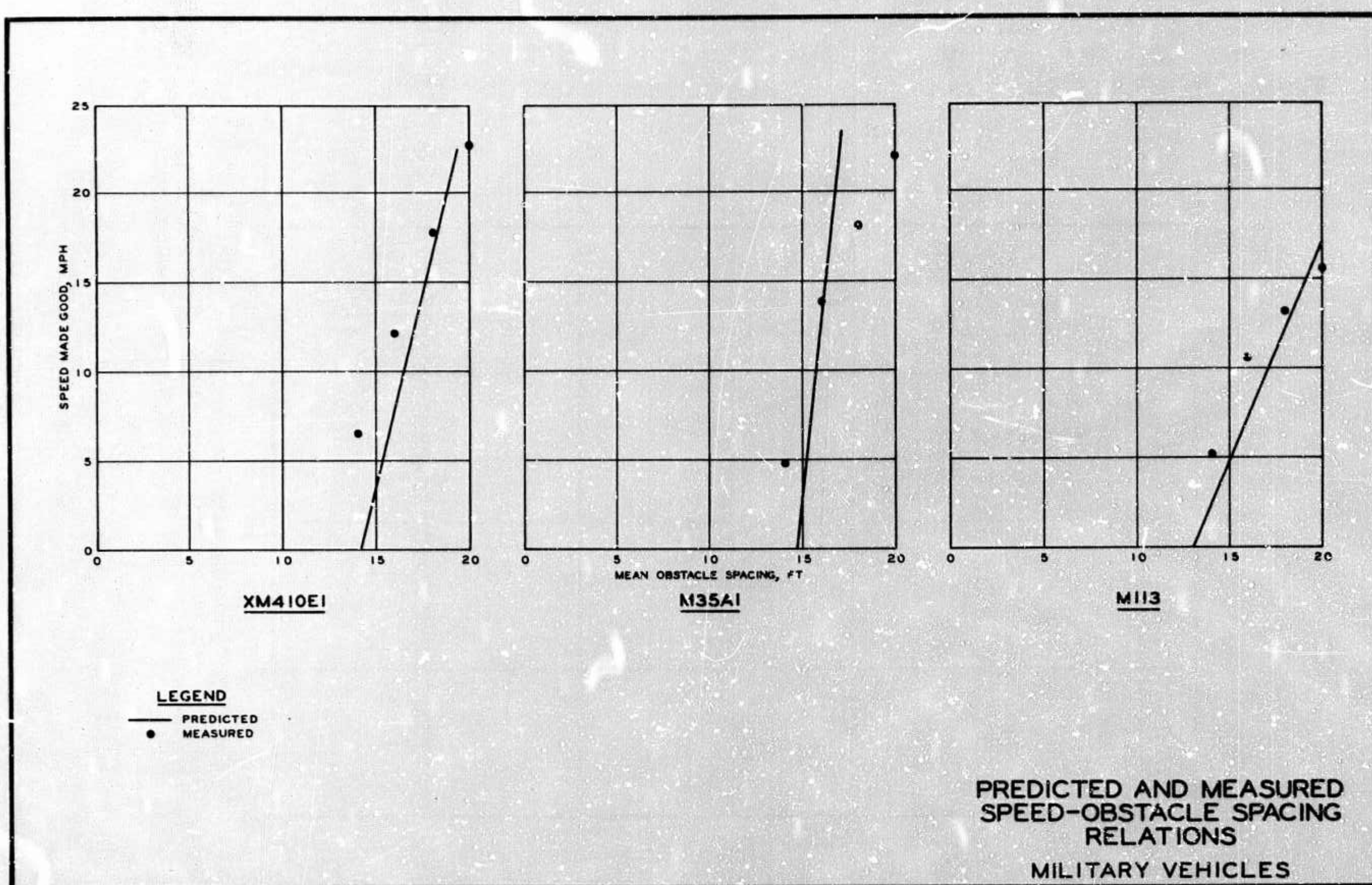


NOTE: MAXIMUM STEERING ANGLE = 30°

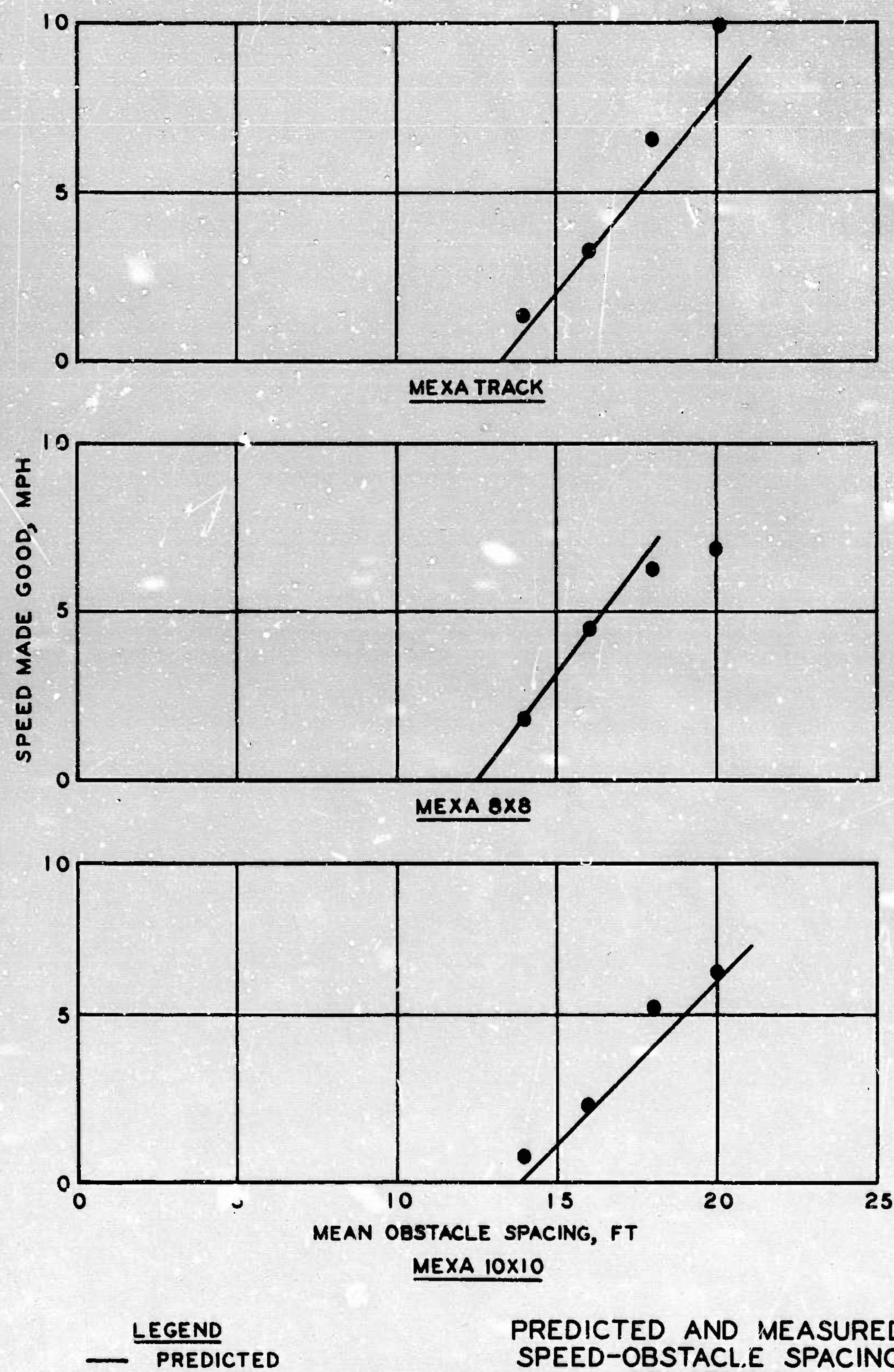
FREQUENCY OF STEERING ANGLE OCCURRENCE
MEXA VEHICLES



AVERAGE STEERING ANGLE
MILITARY AND MEXA VEHICLES



SPEED MADE GOOD, MPH
MEAN OBSTACLE SPACING, FT
XM410E1
M35A1
M113
LEGEND
PREDICTED
MEASURED
PREDICTED AND MEASURED
SPEED-OBSTACLE SPACING
RELATIONS
MILITARY VEHICLES



PREDICTED AND MEASURED SPEED-OBSTACLE SPACING RELATIONS

MEXA VEHICLES

APPENDIX A: USE OF SPEED-OBSTACLE SPACING PREDICTIONS AS INPUT DATA FOR WES ANALYTICAL MODEL

1. The WES analytical model for predicting cross-country vehicle performance uses as one set of input data the relation between vehicle speed and percent area denied to account for performance in lateral obstacles. The following paragraphs will explain the relation between the speed-obstacle spacing curves presented in the main text of this report and the speed-area denied curves required as input data.

2. The structural cell concept relation[4*] presented in paragraph 9 of the main text relates the mean spacing of stems (lateral obstacles) to total area and the number of stems contained within the area. Twenty stems comprise each structural cell. When the area of the structural cell is divided by the number of stems (20), the result is the average or mean area occupied by one stem. The relation between the diameter of the area occupied by each stem (d_s) and the structural cell diameter (D_c) is

$$\frac{20\pi d_s^2}{4} = \frac{\pi D_c^2}{4}$$

or

$$20d_s^2 = D_c^2 \tag{A1}$$

By definition

$$d_s = S_m \tag{A2}$$

where S_m = mean spacing of stems

Substituting equation A2 into equation A1 results in the equation

$$20S_m^2 = D_c^2 \tag{A3}$$

The equation relating percent area denied to the structural cell[1] is

---

* Raised numbers refer to similarly numbered items in the Literature Cited at the end of the main text.

$$\%A_d = \frac{20(\bar{d}_s + W)^2}{D_c^2} \times 100 \qquad (A4)$$

where

d_s = diameter of stem, in.

W = width of vehicle, ft

D_c = diameter of structural cell, ft

Substituting equation A3

$$D_c^2 = 20S_m^2$$

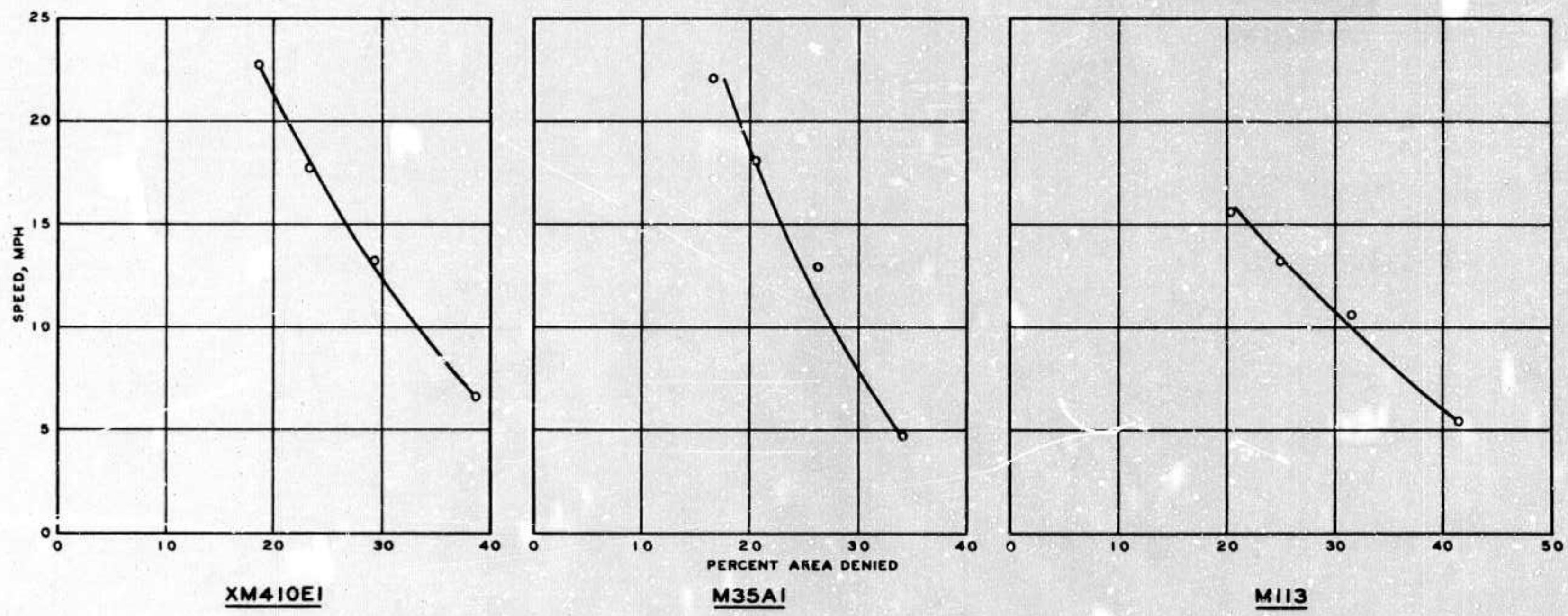
into equation A4, the area denied equation then relates to the mean spacing of the obstacles by

$$\%A_d = \frac{(\bar{d}_s + W)^2}{S_m^2} \times 100 \qquad (A5)$$

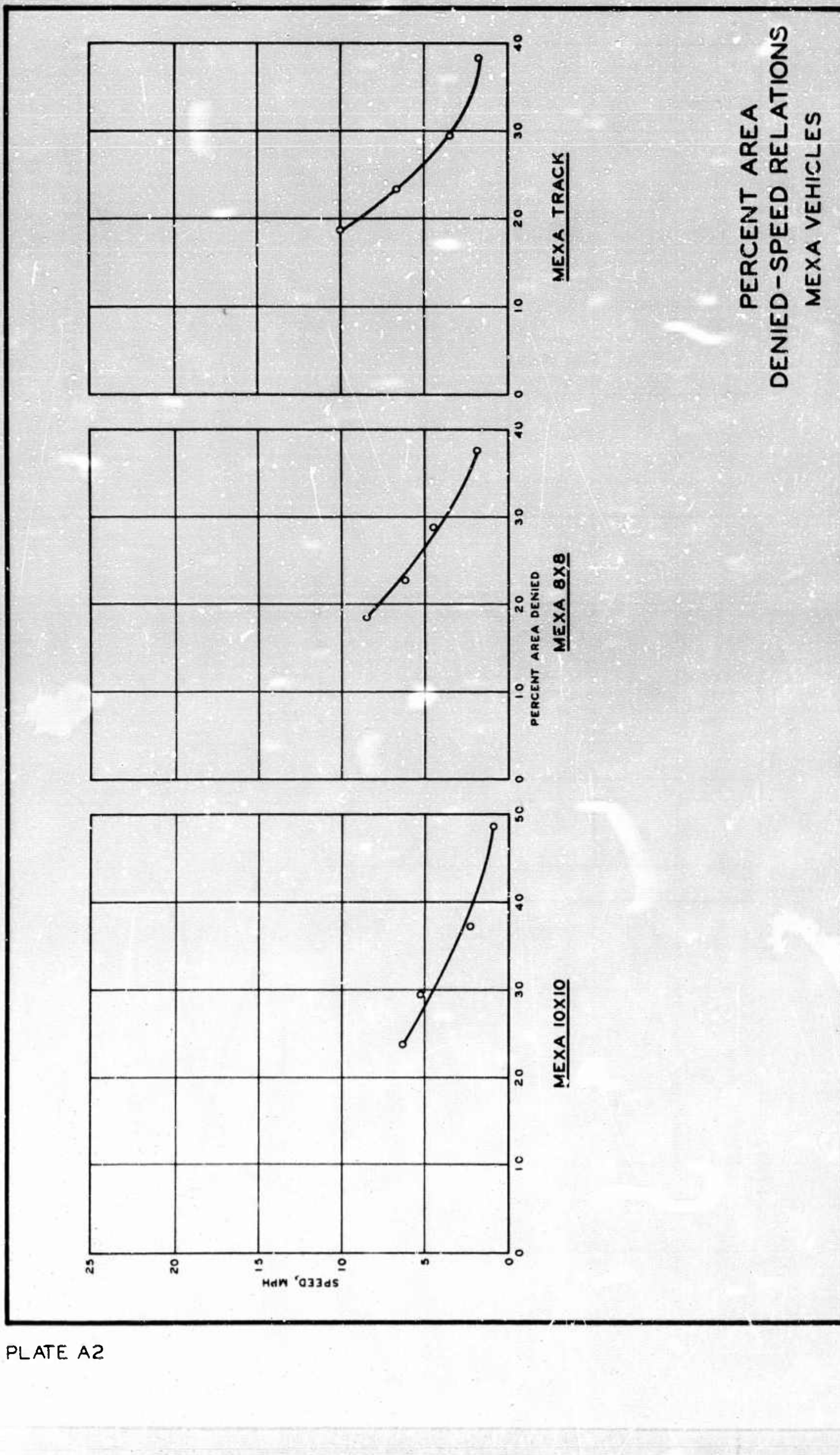
This equation was used to compute the area denied for the four lateral obstacle spacings and six vehicles used in the test program described in the main text. A stem diameter of 2 in. was used in the area denied calculations.

3. The percent area denied-speed curves for the six vehicles tested are shown in plates A1 and A2.

4. It should be noted that the force relations presented in the prediction techniques are acceptable in their presented forms as input data for the WES analytical model.



PERCENT AREA
DENIED-SPEED RELATIONS
MILITARY VEHICLES



PERCENT AREA
DENIED-SPEED RELATIONS
MEXA VEHICLES

PLATE A2

Unclassified

Security Classification

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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13. ABSTRACT

The purpose of this study was to develop pertinent vehicle-lateral obstacle relations for three vehicle test beds (MEXA vehicles) and three conventional military vehicles all having approximately the same payload and to compare the performances of the MEXA vehicles with those of the conventional vehicles. An additional purpose was to develop a method of predicting the speed of a vehicle maneuvering in lateral obstacles. The vehicles were tested on a firm, level surface upon which was imposed a statistically designed array of obstacles at mean spacings of 14, 16, 18, and 20 ft. In 78 of the 118 tests conducted, continuous measurements were made of vehicle speed, drive-line torque, and steering angle. In all tests, measurements were made of time elapsed and distance traveled. The data collected permitted the development of useful relations between vehicle width and minimum obstacle spacing negotiable, vehicle speed and obstacle spacing, vehicle steering angle and obstacle spacing, and vehicle speed and obstacle clearance. These relations were used to develop a simple method for relating the maximum speed a vehicle can develop to obstacle spacing that requires only a knowledge of the vehicle width and its speed-traction characteristics on a firm surface. The conventional vehicles traveled faster and required less arduous steering than the MEXA vehicles. The maximum spacing required by each vehicle appeared to be a direct function of its width; all vehicles required the same minimum clearance on the driver's side. Appendix A describes the use of speed-obstacle spacing relations as input data for an analytical model.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Field tests						
MEXA (Mobility Exercise A) test program						
Military vehicles						
Mobility						
Obstacles						

Unclassified

Security Classification